

USGS-NPS National Vegetation Mapping Program: Sunset Crater Volcano National Monument, Arizona, Vegetation Classification and Distribution

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LIST OF ABBREVIATIONS AND TERMS

| | |
|-----------------|--|
| AA | Accuracy Assessment |
| ABI | Association for Biodiversity Information (offshoot from TNC) |
| AML | Arc Macro Language |
| BOR | Bureau of Reclamation (Also USBR) |
| BRD | Biological Resource Discipline of the USGS |
| CBI | Center for Biological Informatics of the USGS/BRD |
| CIR | Color Infra-Red photography |
| CPRS | Colorado Plateau Research Station of the USGS/BRD |
| DEM | Digital Elevation Model |
| DLG | Digital Line Graph |
| DOQQ | Digital Orthophoto Quarter Quad(s) |
| DRG | Digital Raster Graphic |
| FGDC | Federal Geographic Data Committee |
| GIS | Geographic Information System(s) |
| GPS | Global Positioning System |
| MMU | Minimum mapping unit |
| NAD | North American Datum |
| NBII | National Biological Information Infrastructure |
| NPS | National Park Service |
| NRCS | Natural Resources Conservation Service |
| NVCS | National Vegetation Classification Standard |
| OHV | Off-Highway Vehicle |
| PLGR | Precision Lightweight GPS Receiver |
| RSGIG | Remote Sensing and Geographic Information Group of the Bureau of Reclamation |
| SBSC | Southwest Biological Science Center of the USGS |
| SUCR | Sunset Crater Volcano National Monument |
| TES | Terrestrial Ecosystem Survey |
| TNC | The Nature Conservancy |
| USBR | United States Bureau of Reclamation |
| USDA-FS | United States Dept. of Agriculture – Forest Service |
| USDA-SCS | United States Dept. of Agriculture – Soil Conservation Service |
| USGS | United States Geological Survey |
| UTM | Universal Transverse Mercator |
| VMP | Vegetation Mapping Program |

SUMMARY

Sunset Crater Volcano National Monument (SUCR) Vegetation Mapping Project was initiated in the spring of 1999 as part of and in accordance with the U.S. Geological Survey-National Park Service (USGS-NPS) Vegetation Mapping Program and was completed in the spring of 2004. The Vegetation Mapping Program is administered jointly by the Center for Biological Informatics (CBI), Biological Resources Discipline (BRD) of the USGS, Denver, Colorado, and was initiated as part of the NPS Inventory & Monitoring Program. The primary goal of the Vegetation Mapping Program is to classify, describe, and map vegetation for approximately 250 NPS units.

This mapping project was performed by the following organizations under contract to the CBI:

- The Remote Sensing and GIS Group (RSGIG), Technical Service Center, Bureau of Reclamation (BOR), Department of Interior, Denver, Colorado
- The Colorado Plateau Research Station (CPRS), Southwest Biological Science Center (SBSC), USGS, Flagstaff, Arizona
- NatureServe, Boulder, Colorado

Sixteen vegetation map classes with five modifiers, three land cover map classes, and six Anderson Level II land-use map classes were used for interpretation of approximately 18,750 acres encompassing the monument (~3,040 acres) and surrounding environs (15,710 acres). Vegetation map classes were determined through extensive field reconnaissance, data collection, and analysis in accordance with the National Vegetation Classification Standard (NVCS). The vegetation map was created from photographic interpretation of 1996, 1:12,000 scale color infrared aerial photographs (0.5 hectare minimum mapping unit). All vegetation and land-use information was then transferred to a GIS database using the latest grayscale USGS digital orthophoto quarter-quads (DOQQs) as the base map and a combination of on-screen digitizing and scanning techniques. Overall thematic map accuracy for the entire mapping effort was assessed at 70.3% using the acceptable error criteria with a Kappa Index of 68.0%. The overall 90% confidence interval is 69.0% to 84.0%.

Final products are presented in this report and on the accompanying CD-ROM (Appendix A).

- Vegetation Classification Descriptions
- Land-use Classification System
- Vegetation Classification Key
- Digital and Hard Copy Vegetation Map
- Digital Project Boundaries
- Digital Field Points Coverage (Observation, Classification, Accuracy Assessment)
- Photos of Field Sites
- Accuracy Assessment Results
- FGDC-compliant Metadata

SUCR and similar National Park vegetation mapping databases can be accessed at the USGS-NPS website: <http://biology.usgs.gov/npsveg>.

1. INTRODUCTION

The Vegetation Mapping component of the NPS Inventory and Monitoring Program is a cooperative effort by the U.S. Geological Survey (USGS) and the National Park Service (NPS) to classify, describe, and map vegetation communities in more than 270 national park units across the United States.

The vegetation mapping efforts are an important part of the NPS Inventory and Monitoring Program, a long-term effort to develop baseline data for all national park units that have a natural resource component. Project activities are based on peer-reviewed, objective science. Comprehensive vegetation information is provided at national and regional levels, while also serving local management needs of individual parks. Stringent quality control procedures ensure that products are accurate and consistent for initial inventory purposes and replicable for monitoring purposes. The spatially enabled digital products produced by these efforts are available on the World Wide Web (<http://biology.usgs.gov/npsveg>).

The goals of these vegetation mapping projects are to provide comprehensive mapping of NPS vegetation resources that:

1. Is highly accurate
2. Meets scientific and FGDC standards
3. Has a nationally consistent, hierarchical, classification scheme
4. Has a level of detail useful to park management
5. Uses existing data when appropriate

This report details the park vegetation mapping study for Sunset Crater Volcano National Monument (SUCR) under the USGS-NPS Vegetation Mapping Program. The vegetation study for SUCR includes these components:

1. Collection and analysis of vegetation data
2. Creation of vegetation and mapping classifications based on the National Vegetation Classification Standard (NVCS)
3. Development of a spatial database of the SUCR vegetation using aerial photography and Geographic Information System (GIS) techniques
4. Production of final products including digital and hard copy vegetation maps, assessed to be at least 80% accurate

Because producing an accurate, detailed, digitized vegetation map is a complicated undertaking, several government agencies and private organizations were involved in the project's successful completion.

The Remote Sensing and Geographic Information Group (RSGIG), United States Bureau of Reclamation (USBR), Denver Federal Center, Lakewood, Colorado¹:

¹ The Remote Sensing and Geographic Information Group, organized in 1975, provides assistance and advice regarding the application of remote sensing and geographic information systems (GIS) technologies to meet the spatial information

1) attended planning meetings, 2) conducted aerial photosignature field review and observation point data collection, 3) provided aerial photointerpretation, 4) attended a vegetation classification map class development meeting, 5) created the GIS vegetation database and 6) provided support and content for the final report.

The Southwest Biological Science Center (SBSC), Colorado Plateau Research Station (CPRS), USGS-BRD, Flagstaff, Arizona¹ 1) attended planning meetings, 2) conducted field data collection and analysis, 3) provided data analysis and classification, 4) prepared the vegetation classification key and descriptions, 5) provided accuracy assessment data collection and analysis, 6) conducted the vegetation map accuracy assessment, and 7) prepared the final project report.

NatureServe's Western Regional Office in Boulder, Colorado² provided a review of CPRS vegetation data analyses and CPRS local vegetation descriptions as well as prepared global descriptions for the vegetation associations determined at SUCR.

¹ The Colorado Plateau Research Station is one of four research stations within the Southwest Biological Science Center. This research station was originally established in 1989 as a National Park Service Cooperative Park Studies Unit at Northern Arizona University in Flagstaff and was merged into the USGS Biological Resources Discipline in 1996. Major categories of research include ecoregional studies and conservation planning; endangered species studies; vegetation distribution, ecology, and dynamics; data management and dissemination; inventory and monitoring studies; and wildlife ecology.

² NatureServe has its roots in The Nature Conservancy (TNC), which in 1974 began establishing and supporting state natural heritage programs. By 1994 the natural heritage programs expanded significantly and The Nature Conservancy established a new network, the Association for Biodiversity Information. Now known as NatureServe, it has assumed in managing the National Vegetation Classification (NVC) and providing scientific and technical support to the network. The NatureServe network now includes 74 independent natural heritage programs and conservation data centers across the Western Hemisphere.

2. PROJECT AREA

Sunset Crater Volcano National Monument (SUCR) was authorized by Congress and the proclamation was signed by President Herbert Hoover in 1930. This 3,040-acre unit features the geologically young and approximately 8,029 ft (2,447 m) high Sunset Crater cinder cone (NPS 1997). SUCR lies approximately 13 miles northeast of Flagstaff, Arizona and is reached via U.S. Highway 89 north of Flagstaff (Figure 1). The monument is best known for extensive geologic processes and exposures relating to volcanism (i.e., cinder cones, cinder beds, and lava flows). Recreational and educational activities include hiking, scenic drives and vistas, wildlife viewing, visitor natural history education, and research opportunities. In addition to the monument, a buffer or environs of approximately 15,710 acres (6,360 hectares) of surrounding USDA Forest Service (USDA-FS) lands and privately owned residential land is also included in the project. The total project area is 18,750 acres (7,590 hectares) (Figure 2).



Figure 1. Location of Sunset Crater Volcano National Monument.

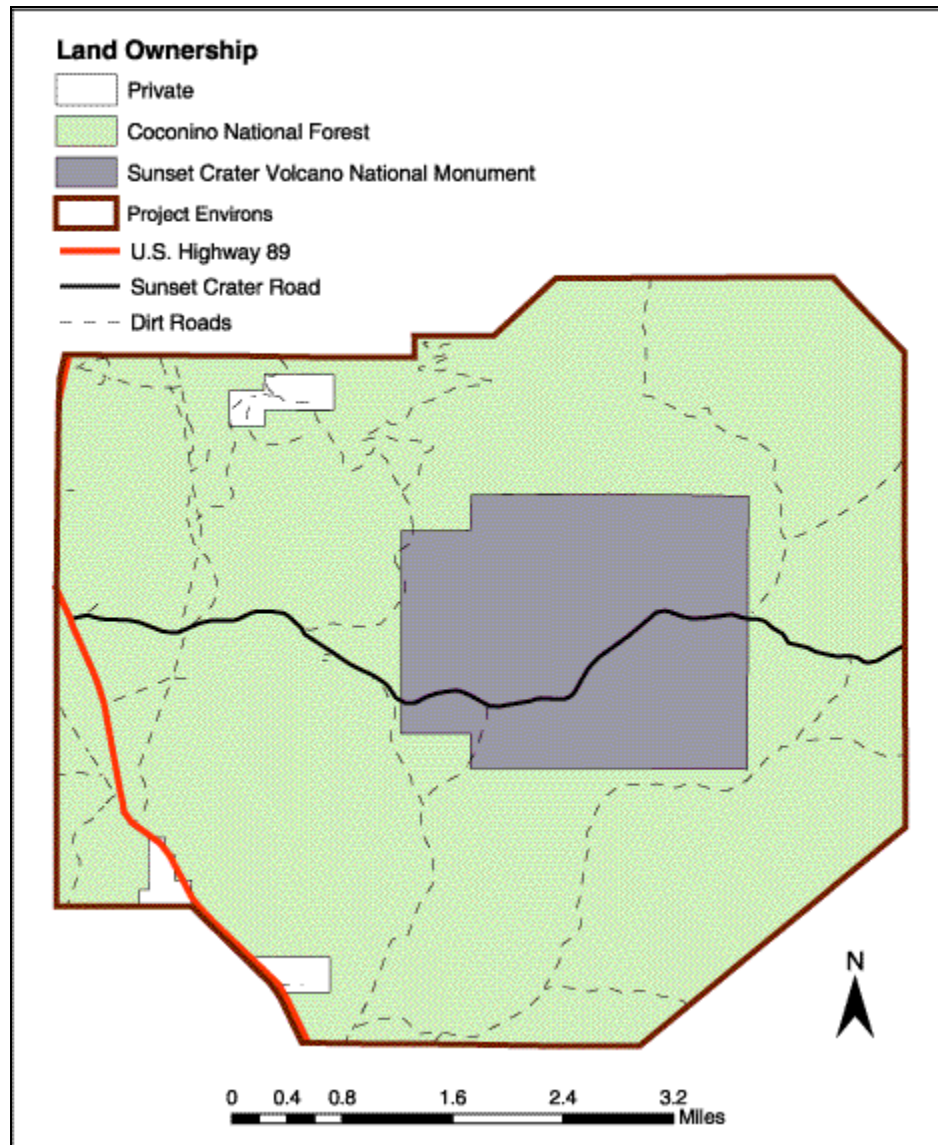


Figure 2. SUCR project boundaries and land ownership.

Location and regional setting

SUCR is situated on the southwestern Colorado Plateau of north-central Arizona, within the San Francisco Peaks Volcanic Field (Cordasco et al. 1998, Zion Natural History Association 1985). It is bounded on the north by O’Leary Peak, Robinson Mountain, Darton Dome, and Black Mountain; to the south by Lenox Crater, Little Cinder Basin, and Double Crater; on the east by Kana-a Wash; and on the west by Bonito Park and U S Highway 89. Access is provided by U.S. Highway 89, as well as county roads and USDA-FS roads through the adjacent Coconino National Forest. The NPS Visitor Center is on USDA-FS managed land just west of the monument at the edge of Bonito Park, and a Visitor Contact Station is maintained at the Bonito Lava Flow inside SUCR. A number of hiking trails and scenic overlooks are maintained in the monument and adjacent project area for visitor access and include the Lava Flow Nature Trail, Lenox Crater Trail, Bonito Park Overlook, Cinder Hills Overlook, and Painted Desert Vista.

Climate

SUCR has a semi-arid, continental climate that includes moderately hot, moist summers and cold, dry winters (Appendix B). Precipitation events, often in the form of violent thunderstorms, occur from July through September. For example, during 1997, NOAA records show that 45% of the annual 20 inches of precipitation fell during this three-month period (Cordasco et al. 1998, NOAA 1997). Summer maximum temperatures range between 80-95 degrees F., while winter minimum temperatures may reach down to -25 degrees F. The prevailing winds are southwesterly.

Geology and topography

SUCR lies near the northeastern edge of the San Francisco volcanic field, which covers approximately 1,800 square miles of the southern Colorado Plateau in north-central Arizona (Priest et al. 2001). The volcanic field, whose major feature is the 12,600 foot high San Francisco Peaks, formed during the latter part of the Cenozoic era. Lava flows, cinders, tuffs, and other volcanic units are well exposed throughout the monument (NPS 1997 and Zion Natural History Association 1985). The monument's namesake landform, Sunset Crater (Figure 3), a cinder cone, is a relatively recent landscape feature that formed during an eruption period that began sometime between 1040 and 1100 A.D. (Ort et al. 2002). This period of activity, was short-lived from a period of days to years, blanketed much of the surrounding area in a thick bed of cinders and produced two contemporaneous lava flows, the Kana-a and the Bonito flow (Ort et al. 2002) (Figure 4).



Figure 3. Sunset Crater cinder cone (foreground) and San Francisco Peaks (background).



Figure 4. Bonito Lava Flow inside Sunset Crater Volcano National Monument.

The volcanic units comprising the San Francisco Peaks Volcanic Field overlie a sequence of ancient, sedimentary rock formations. These Precambrian and Paleozoic strata are the same or similar units seen in the Grand Canyon to the northwest (Chronic 1988). Many of the sedimentary rocks underlying the region formed in a number of environments associated with an ancient sea. Sandstones formed as outwash deposited on low-lying plains or as remnants of ancient sand dunes, and shales and limestones formed as the region was periodically submerged under a transgressing sea (Zion Natural History Association 1985). Subsequent uplift of this massive sequence of rocks promoted erosion that later exposed several of these older sedimentary units. These are most readily seen in the Painted Desert to the north and east of SUCR, but also can be seen in other localities to the west and south.

The SUCR landscape contains outcrops and slopes of both basalt and more silicic rocks, exposed beds of volcanic tuff, some with high iron concentrations, aa lava flows, and cinder hills and beds ranging from black to reddish brown in color (Figure 5). Because of northern Arizona's relatively cool dry climate, Sunset Crater and other volcanic features of the monument have not weathered significantly since their formation. The porous nature of the cinders resists furrowing by runoff. However, lichens now cover much of the lava, and areas of vegetation occur in pockets where humus has built up from wind-blown pine needles, cinders, and decayed plant matter.



Figure 5. Black cinder beds and adjacent cinder cone, Lenox Crater, among ponderosa pine trees and apache plume shrubs.

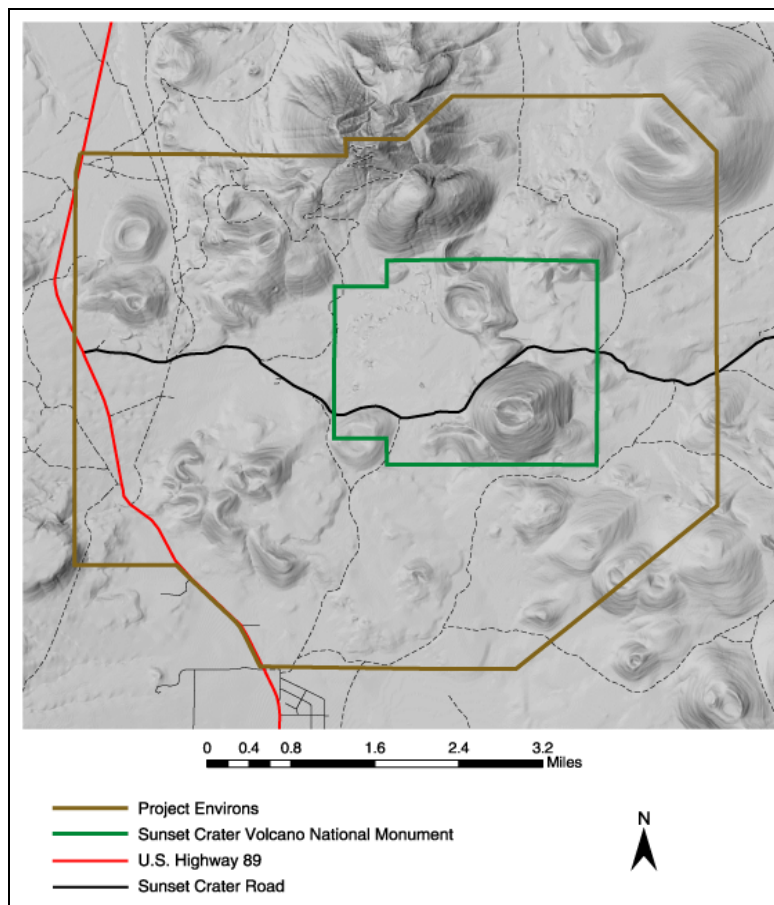


Figure 6. Shaded relief map of the project area.

Topography of SUCR consists of steep peaks, rolling hills, slopes, broad flats, and small drainages (Figure 6). The elevations of several prominent landscape features are as follows: O'Leary Peak (2,355m/8,940ft), Darton Dome (2,560m/8,410ft), Black Mountain (2300m/7,555ft), Robinson Mountain (2,400m/7,911ft), Sunset Crater (2,450m/8,039ft), and Lenox Crater (2,210m/7,250ft). Lower elevation flats include Kana-a Wash (2,040m/6,700ft), Bonito Park (2,100m/6,900ft), and just outside the monument boundary, Cinder Lake (2,010m/6,660ft). Though the cinders, lava flows, and cinder cone of Sunset Crater are the park's major features, other volcanic landforms are evident, in particular O'Leary Peak and Darton Dome, two steep-sided dacite domes along the park's northern boundary.

Wildlife

The ponderosa pine (*Pinus ponderosa*) woodland that covers much of SUCR strongly influences the fauna of the area. This is particularly true for the birds, with many of the most common and most conspicuous species at the monument being those typical of ponderosa pine woodlands. Such species include Lewis' Woodpecker (*Melanerpes lewis*), Steller's Jay (*Cyanocitta stelleri*), Mountain Chickadee (*Parus gambeli*), Pygmy Nuthatch (*Sitta pygmaea*), Yellow-rumped Warbler (*Dendroica coronata*), and Grace's Warbler (*Dendroica graciae*). Other common and frequently seen small birds in and around the monument include Williamson's Sapsucker (*Sphyrapicus thyroideus*), Pinyon Jay (*Gymnorhinus cyanocephalus*), Clark's Nutcracker (*Nucifraga columbiana*), Western Bluebird (*Sialia mexicana*), Western Tanager (*Piranga ludoviciana*), and Dark-eyed Junco (*Junco hyemalis*). Among larger birds, the most commonly seen species are Common Raven (*Corvus corax*), Turkey Vulture (*Cathartes aura*), and Red-tailed Hawk (*Buteo jamaicensis*). Occasional Golden Eagles (*Aquila chrysaetos*) may be seen at any time of year, and Bald Eagles (*Haliaeetus leucocephalus*) are present in small numbers during the winter.

The most conspicuous small mammal at the monument, the Abert's squirrel (*Sciurus aberti*), is also closely associated with ponderosa pine for both food and nest sites. Although not as frequently seen, porcupines (*Erethizon dorsatum*) are also fairly common and frequently found in ponderosa pine. Other common small mammals include desert cottontail (*Sylvilagus audubonii*), deer mouse (*Peromyscus maniculatus*), and pinyon mouse (*P. truei*). Among larger mammals, there are a variety of small and medium-sized carnivores in and around SUCR. Most frequently seen are coyotes (*Canis latrans*) and raccoons (*Procyon lotor*), particularly around the campground and housing area. The gray fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), striped skunk (*Mephitis mephitis*) and long-tailed weasel (*Mustela frenata*) are also present. Black bears (*Ursus americanus*) and mountain lions (*Felis concolor*) are both present at least occasionally, but are rarely seen. Among ungulates, mule deer (*Odocoileus hemionus*) are the most common native species at SUCR. Elk (*Cervus elaphus*) were not originally native to northern Arizona, but introduced animals have expanded into the area and small numbers are now seen seasonally. Herds of pronghorn (*Antilocapra americana*) occur in grasslands and one-seed juniper (*Juniperus monosperma*) savannas at lower elevations, and migrate seasonally to the vicinity of SUCR. Javelina (*Pecari tajacu*) are a new addition to the mammal list. This species has been expanding its range northward from southern and central Arizona, and individuals have recently been recorded within the monument boundaries.

The amphibian and reptile fauna at SUCR is depauperate, because of the relatively high elevation and dry conditions. No amphibian species have been positively documented at the monument, though there is an unconfirmed report of tiger salamander (*Ambystoma tigrinum*). The most conspicuous lizard species in and around the monument are the eastern fence lizard (*Sceloporus undulatus*) and tree lizard (*Urosaurus ornatus*). The greater short-horned lizard (*Phrynosoma hernandesi*) and plateau striped whiptail (*Cnemidophorus velox*) are also present, but are not as frequently seen. Only two snakes are known from the immediate area of the monument: the gopher snake (*Pituophis melanoleucus*) and the western rattlesnake (*Crotalus viridis*); although both are rare at this elevation.

Vegetation

Vegetation of SUCR and its environs is diverse, including nearly barren beds of cinder or lava and rock outcrops, to grassy meadows, open stands of trees with sparse understory shrublands, and dense forests on more moist aspects of the highest slopes, drainages, and ridges (Figure 7). SUCR is probably most noted for the sparsely vegetated cinder cones, lava beds, and lava rock outcrops. Most of these geologically dominated landform features consist of very sparse to no vegetation and cover approximately 20% of the project area.

Woodlands, which are open forest canopies, dominate the project area and occur on flats, slopes, hills, drainages, and ridges. The most common tree species in the project area is ponderosa pine (*Pinus ponderosa*). Ponderosa pine woodlands are typically found on cinder soils with little to no understory cover. Ponderosa pine may be present in nearly pure stands or may intermix with other coniferous trees common to the area, including Douglas-fir (*Pseudotsuga menziesii*), limber pine (*Pinus flexilis*), pinyon pine (*Pinus edulis*), and Utah juniper (*Juniperus osteosperma*). The second most common tree species is pinyon pine and often co-occurs with Utah juniper. Limber pines and Douglas-fir are confined to a mixed conifer zone on O'Leary Peak and Darton Dome. Small stands of quaking aspen (*Populus tremuloides*) are present throughout the project area. Quaking aspen grow along the edges of lava beds, within the lava beds, and in small stands on O'Leary Peak and Darton Dome, often adjacent to stands of Douglas-fir.

Shrublands occur mainly in small patches on rock outcrops, on sparse cinder slopes, in the openings of woodland canopies, and can co-dominate with grasses in open meadows. Shrublands are rarely observed without seedling or sapling trees present. The most widely distributed and common shrub is Apache plume (*Fallugia paradoxa*); it occurs on sparse cinder slopes and is also a common understory shrub. Other shrubs which dominate small stands or patches in lava outcrops, on scree, and rock outcrops include rabbitbrush (*Ericameria nauseosa*), three-leaved sumac (*Rhus trilobata*), ocean spray (*Holodiscus dumosus*), pericome (*Pericome caudata*), brickellbush (*Brickellia californica*), and wax currant (*Ribes cereum*).

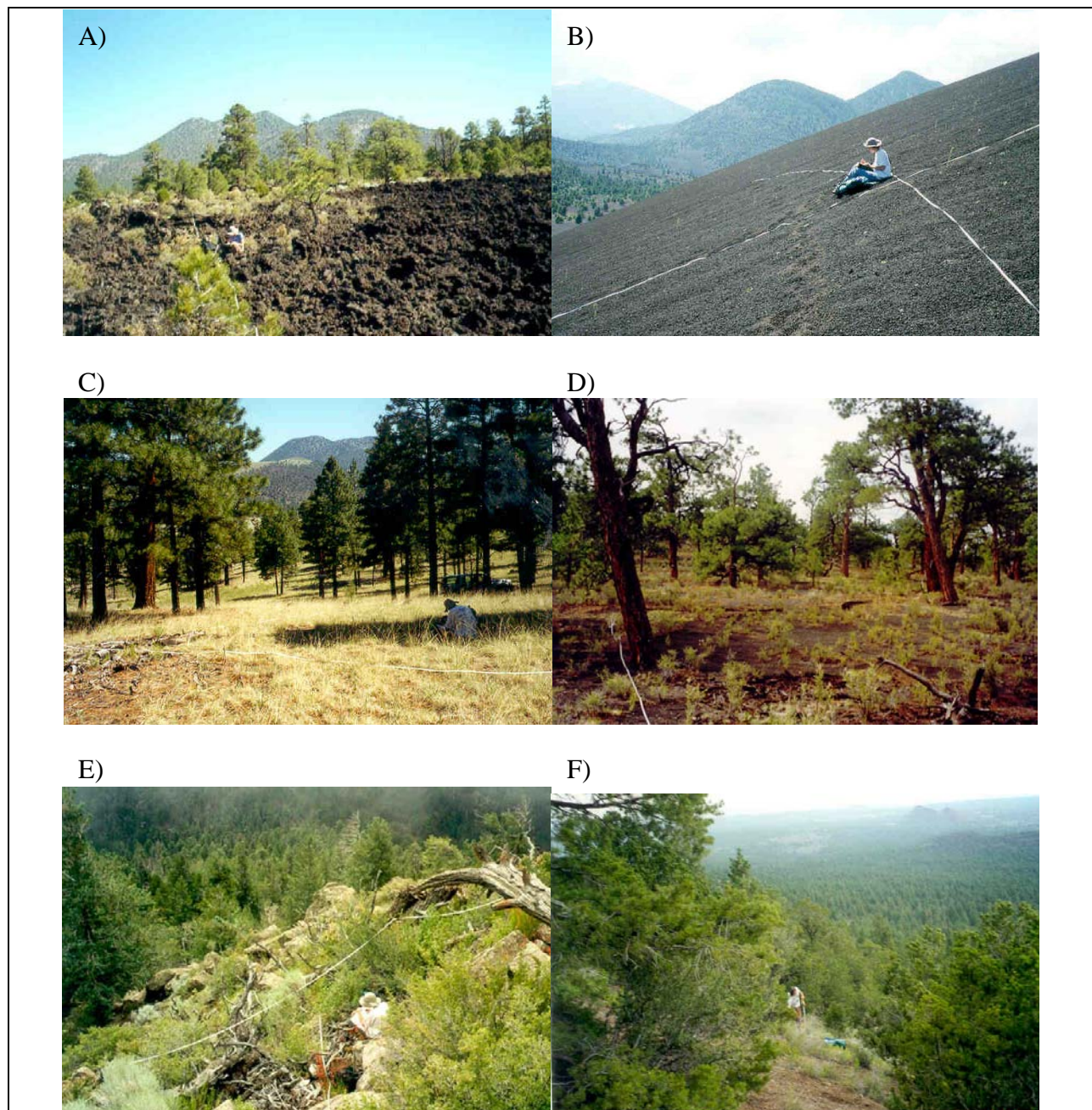


Figure 7. Vegetation typical of SUCR includes A) islands of vegetation in lava beds, B) sparsely vegetated cinder barrens, C) grassy meadows within surrounding woodlands, D) sparse shrub understory in open woodlands and E) and F) dense forests at higher elevations.

Grasses commonly occur as the understory in tree canopies, in smaller patches between tree canopies, as well as in more open meadow-like areas. Blue grama (*Bouteloua gracilis*) and mountain muhly (*Muhlenbergia montana*) are the dominant species in these grassland areas.

Blue grama is the most common grass species. It occurs in larger meadows or parks, such as Bonito Park (an open-grassland area west of SUCR that is co-managed by the USDA-FS) and often is in vegetation co-dominated by rabbitbrush (*Ericameria nauseosa*). Less common in the grassland patches are western wheatgrass (*Pascopyrum smithii*) and sand bluestem (*Andropogon hallii*). Sand bluestem is a bunchgrass that occurs mostly in sparse patches in the eastern section of the project area. Western wheatgrass is often used in re-seeding efforts (FEIS 2001) and is found mainly in the recently burned areas northwest of the monument. Disturbed areas also facilitate introduced annual grasses, particularly cheatgrass (*Bromus tectorum*), native forbs such as meadow-rue (*Thalictrum fendleri*) and Carruth's sagewort (*Artemisia caruthii*), and non-native species such as toadflax (*Linaria dalmatica ssp. dalmatica*) and mullein (*Verbascum thapsus*).

Land use

Various types of land use occur in the project area today; however, mapped land use (including transportation, communication, and utility areas; facilities; residential land; reservoirs and trick tanks; strip mines, quarries, and gravel pits; and croplands and pastures) covers less than 1% of the project area (480 acres). Historically pioneers altered the landscape for agricultural activities, resulting in remnant historic agricultural fields that are visible on the aerial photography.

Current land use includes access/recreational roads and trails, monument and USDA-FS facilities, pumice quarry sites, residences, and limited amounts of agricultural activity. Pumice is mined to incorporate into soap products and is also used in the stone-washed blue jean manufacturing process. U. S. Highway 89 was widened through the project area during the course of the study, resulting in land use changes that are not evident on the 1996 aerial photos used in this project.

South of the monument, off-highway vehicle (OHV) use on cinder beds is heavy, resulting in unsightly tracks, damage to, and in some cases elimination of, sparse vegetation, and introduction sites for exotic plant species including knapweed (*Centaurea* spp.). OHV tracks, as seen on the 1996 aerial photographs, were mapped. These tracks are constantly changing and it is likely that they will need to be re-evaluated for current extent of OHV use in and around the monument. Residential housing in the southern section of the project environs, specifically Lenox Park, has also increased since the 1996 aerial photography was acquired. A controlled burn also occurred in the project environs since 1996, possibly changing understory species composition and density as delineated in the photography.

3. METHODS

In mapping and classifying the vegetation of SUCR, we used the protocols and procedures established by the USGS/BRD (Appendix C) and described in *Field Methods for Vegetation Mapping, Standardized National Vegetation Classification System* (TNC and ERSI 1994a). The general work tasks were:

1. Project scoping and planning
2. Existing information review
3. Preliminary data collection
4. Aerial photography and base map acquisition
5. Sampling design development
6. Field data collection
7. Vegetation classification and characterization
8. Vegetation map preparation
9. Accuracy assessment

Project scoping and planning

SUCR vegetation mapping incorporated the combined expertise and oversight of several organizations: 1) oversight and programmatic considerations were managed by the Center for Biological Informatics (CBI) of the USGS/BRD, 2) NPS and SUCR personnel provided additional guidance on specific monument needs, 3) aerial photointerpretation and cartographic mapping were provided by the USBR/RSGIG, 4) the CPRS provided field data collection, data analysis, the plant association local descriptions and key, and accuracy assessment, and 5) NatureServe provided data analysis review and the global plant association descriptions. The specific technical responsibilities assigned to the cartographic and ecological teams are listed below:

RSGIG responsibilities and deliverables

1. Obtain existing color-infrared aerial photography from NPS
2. Collect photointerpretive observation point data to determine photosignatures, determine a preliminary classification, and familiarize interpreters with plant community characteristics and their range of variation
3. Prepare a preliminary photointerpretation to assist field data gathering efforts
4. Attend a meeting to determine final mapping classes, both vegetated and land use, to be used for the final photointerpretation
5. Interpret aerial photographs
6. Transfer interpreted information to a digital spatial database and produce hard copy (paper) vegetation maps
7. Create digital vegetation coverages including relevant attribute information
8. Conduct field verification of the accuracy of the draft vegetation map
9. Produce Arc/Info export file of photointerpretive observation point locations
10. Provide any ancillary digital files developed during the mapping process
11. Document FGDC compliant metadata files (Appendix A) for all created spatial data

12. Prepare materials for the final report describing procedures used in preparing products

CPRS responsibilities and deliverables

1. Develop a preliminary vegetation classification for the study area from existing data
2. Determine field data sampling locations and strategy
3. Collect field data to identify and describe plant associations in the project area
4. Analyze field data and prepare a final classification, local association descriptions, and a key to plant associations
5. Field test the final classification, descriptions, and plant association key
6. Collect accuracy assessment points, analyze them against the final photointerpretation and prepare statistics describing map accuracy
7. Produce Arc/Info export file of sampling locations, vegetation relevé and accuracy assessment locations, and Access database file of relevé and accuracy assessment data and jpeg image files of relevé photos
8. Develop FGDC compliant metadata files (Appendix A) for all vegetation classification relevés and accuracy assessment observation coverages and databases.
9. Prepare a final report CD with all compiled products

NatureServe responsibilities and deliverables

1. Review vegetation classification developed by CPRS
2. Develop global plant association descriptions
3. Include newly described plant associations into National Vegetation Classification Standard (NVCS) and present on a public web site (www.natureserve.org/explorer/)

A scoping meeting was held in March 1999 at the NPS office in Flagstaff, AZ with all interested parties. The purpose of this meeting was to inform monument staff and interested neighbors about the USGS-NPS Vegetation Mapping Program, learn about the monument's management and science issues and concerns, identify existing data sources, develop a preliminary schedule with assigned tasks, obtain a commitment from the monument to issue collecting permits, identify possible areas of cooperation with neighbors and partners, and define project boundaries.

Park management issues and concerns that a vegetation map could help with were identified during the scoping meeting and included: to identify quaking aspen (*Populus tremuloides*) stands, to better understand the microhabitats and vegetation communities associated with the lava flows, to determine the stand structure of the ponderosa pine (*Pinus ponderosa*) communities, to understand the importance of Bonito Park to Native American communities, and to protect the rare endemic species Sunset Crater Penstemon (*Penstemon cluteii*).

The total mapping area was set at 18,750 acres, including 3,040 acres within SUCR. This boundary was selected in order to include a 1-mile buffer area around the monument and other areas of special interest such as Bonito Park.

Preliminary data collection and review of existing information

To minimize duplication of previous work and to aid in the overall mapping project, we obtained existing data including maps and reports from various sources. Monument staff provided digital and/or hard-copy background maps for the project border and miscellaneous other digital files. We obtained site maps from the NPS and the Coconino National Forest, and topographic maps, digital elevation models (DEMs), digital line graphics (DLGs), and digital raster graphics (DRGs) from the USGS. Babbitt Ranches provided a copy of their recently completed Biological Assessment (Cordasco, et al. 1998). A preliminary list of plant associations and local land use types was prepared following a field reconnaissance survey conducted at the time of the scoping meeting.

Aerial photography and base map acquisition

Aerial photography covering the entire project area was received by RSGIG from USGS/BRD. The color infrared (CIR) photographs were acquired on October 8, 1996 by Merrick, & Company, Aurora, Colorado, and were taken at 1:12,000 (1inch=1,000 feet) scale. Hardcopies of the photographs were provided as 9 inch x 9 inch diapositives. Overlap for these photos averaged approximately 50-60% and sidelap between flight lines is approximately 30-40%. Flight lines for the aerial photos are shown in Figure 8. The team used these photos primarily for delineation of vegetation map classes and secondarily to inform field characterization of the vegetation.

The base maps, standard USGS digital orthophoto quarter quads (DOQQs) for geo-referencing or registration of delineated map classes were created from aerial photographs flown in October 1997. These maps are grayscale, with 1 meter per pixel resolution, UTM coordinate system, and NAD83 datum. The DOQQs used for this project are O'Leary Peak (SE and SW quarter-quads), Strawberry Crater (SW quarter-quad), Sunset Crater East (NW quarter-quad), and Sunset Crater West (NE and NW quarter-quads).

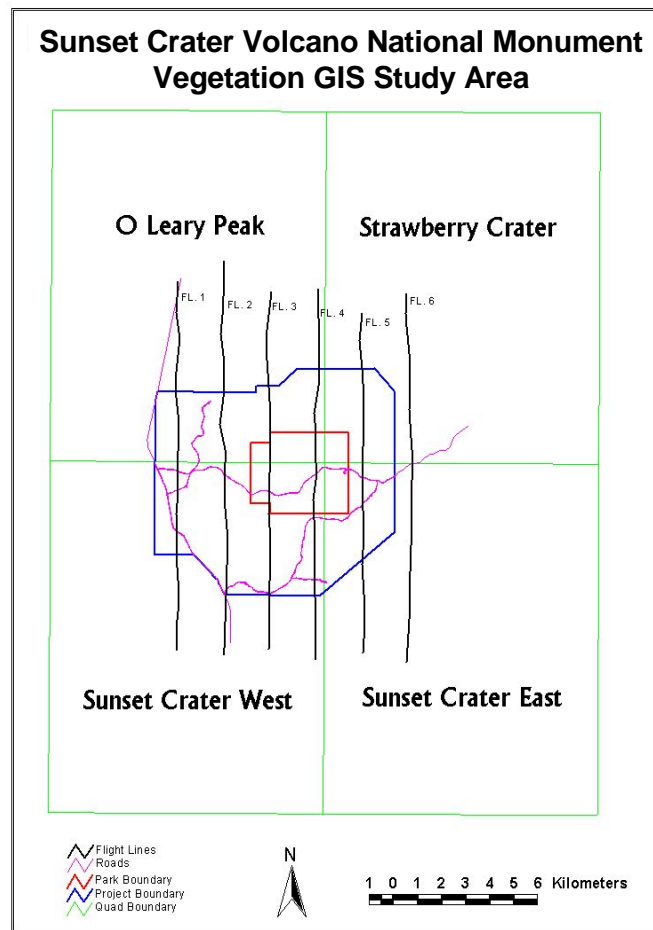


Figure 8. Mapping project area and aerial photo flightlines.

Sampling design development

A gradsect sampling design was used to divide the park into 'environmental types' to stratify for field sampling. The environmental types were developed using habitat types identified in the USDA-FS Terrestrial Ecosystem Survey (TES) mapping (Miller et al. 1991). We also identified, in a scoping session with USGS, BOR, and NPS scientists and managers, four additional aspect and elevation characteristics that could be derived from a Digital Elevational Model (DEM). We developed a digital map (coverage) of environmental types in a GIS by overlaying a coverage of habitat types and the four derived topographic characteristics. The result was 40 possible 'environmental types'. A total of over 100 potential relevé locations were allocated among the environmental types based on the percent contribution of each environmental type to the total study area. The allocated relevés were used to guide sampling. Within the environmental types we initially determined placement of relevés based on road accessibility and land ownership access.

Several environmental types were inaccessible due to extensive sharp lava beds causing high safety risks for the field crew. The Center of Biological Informatics (CBI) lent the field team laser binoculars. The binoculars provide locality information in UTM, using the distance and azimuth offset of targeted locations in conjunction with the GPS Precision Lightweight GPS

Receiver (PLGR) system. Additional laser relevés were completed in SUCR until all environmental types within the gradsect sampling area were sampled.

Field data collection

RSGIG staff conducted field surveys in support of the aerial photointerpretation in June 1999, with some follow-up work to clarify photosignatures in early May 2000. Two RSGIG plant ecologists collected the data and simultaneously took representative photographs of plant associations and their position in the landscape. These observation points were used to describe the plant association characteristics and their occurrence relative to aerial photosignatures. Field notes were transcribed directly on Mylar overlays of aerial photography. The RSGIG team also conducted joint field sessions with CPRS plant ecologists to exchange observations, observe field methodologies for vegetation classification relevé data collection, and discuss the project area.

RSGIG ecologists collected data at 46 photointerpretive observation points to document the plant association characteristics associated with particular photographic signatures. Photointerpretive observation points also helped the photointerpreters understand the range of variation of each plant community. In general, sampling included basic information on habitat and vegetation structure and composition. Specific information recorded included UTM coordinates using the NAD83 datum, dominant species cover data, and a brief summary of environmental characteristics. The datasheet used to collect the photointerpretive observation points can be located in Appendix D.

A two person team of CPRS plant ecologists conducted field surveys from mid-June thru mid-August 1999 and sampled 114 field relevés in the project area. The standard relevé method was used to quantify the vegetation community (Muller-Dombois and Ellenberg 1974, USGS-NPS 2000). The field team subjectively determined field relevé positioning within each environmental type visited so as to represent vegetation assemblages that were relatively dominant, homogenous, and covered a minimum mapping unit area of half a hectare. The field team also sampled special features and unique vegetation types within the environmental assemblages that are of specific interest to the park.

Typically we measured 1,000m² circular relevés; however, in areas of dense vegetation we would lower our relevé size to 400m². We selected 1000m² relevé as our standard as the vegetation of the area is relatively sparse and this size better represents the 0.5ha minimum mapping unit (MMU) than a 400m² relevé (20% vs. 8%). Other vegetation studies of arid lands have also used this relevé size (Thomas et al 2003) and State Heritage ecologists recommended this size for arid and semi-arid vegetation (T. Keeler-Wolf pers. comm.). Additionally, if the patch shape was better represented by rectangular or square relevés we used this relevé layout instead, as in lava bed outcrops. The habitat of the site was characterized by the relevé slope, aspect, elevation, soil characteristics, topographic position, landform type, and whether it was wetland or upland. We also took two photographs that best represented the vegetation of the site and recorded the angles they were photographed from. We documented site UTM coordinates, landownership, and USGS quad. We recorded leaf phenology, leaf type, and physiognomic class for the overall vegetation. For all perennial species we also recorded strata layer (tree, shrub, and ground) and percent species cover. Total cover for all vegetation was estimated for each strata layer (total tree, shrub, and

ground cover). We also measured each tree with >10cm dbh (diameter at breast height). In addition, we included calculations of percent cover for exotic species, individually and combined. Similarly, we measured percent cover for all sensitive species (as identified by the NPS). The classification relevé datasheet is located in Appendix D.

The relevé data was entered into a Microsoft Access 2000 (version 9.0) database. Plant names were standardized to the USDA PLANTS (USDA NRCS 1999) nomenclature. After the data was entered we performed spatial and data entry quality control checks.

Vegetation classification and characterization

Vegetation classification was based on guidelines developed from the National Vegetation Classification (NVC) (TNC and ERSI 1994b) and the National Vegetation Classification Standard (NVCS) adopted by the FGDC (1997). The NVCS classifies vegetation on seven hierarchical levels with the finest levels of the classification being the alliance and the association (Figure 9).

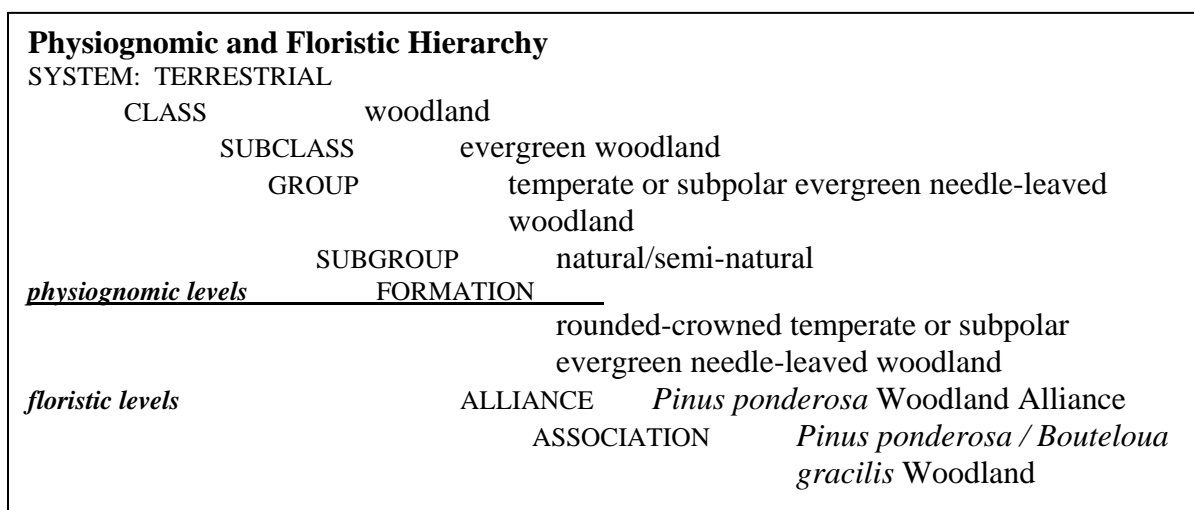


Figure 9. An example of the NVCS physiognomic and floristic hierarchy using the *Pinus ponderosa* / *Bouteloua gracilis* association.

The goal of the USGS-NPS Vegetation Mapping Program is to classify vegetation types to the association level. The definition of an association as put forward by the Ecological Society of America Vegetation Classification Panel is “A vegetation classification unit consistent with a defined range of species composition, diagnostic species, habitat conditions, and physiognomy” (Jennings et al. 2003). Occasionally, a vegetation type cannot be defined to the association level, and the vegetation is described to the courser alliance level. An alliance consists of a group of plant associations that share a uniform physiognomy and is characterized by one or more diagnostic species, which at least one of these species is found in the uppermost vegetation stratum (Mueller-Dombois and Ellenberg 1974).

Associations are named by the dominant and/or indicator species occurring in the community. If more than one species is characteristic of the association, then the species in the dominant strata is listed first and separated by a forward slash (/) from species in the lower strata, or if species occur in the same strata they are separated by a dash (-). Parentheses are used when species are frequently present, but do not necessarily occur all the time, yet are considered an important part of the community structure when present. The nomenclature for alliances is based on the dominant and diagnostic species, and includes at least one species from the uppermost stratum in the alliance name.

Vegetation was initially analyzed using multivariate classification analyses. Matrices of species absolute cover organized by relevé and species were extracted from the field relevé for use in a vegetation classification and ordination software program, PC-Ord, v 4.10 (McCune and Mefford 1999). Six matrices based on division of relevés by lifeform were examined: 1) all relevés, 2) relevés with greater than 60% cover tree species, 3) relevés with greater than 25% (but less than 60%) cover tree species, 4) relevés with greater than 25% cover shrub species (and less than 25% cover tree and herbaceous species), 5) relevés with greater than 25% cover grass and forb species (but less than 25% cover tree or shrub species) and 6) relevés with less than 25% cover. The cover of trees, shrubs or grasses in a relevé was calculated by adding the separate cover estimates for each species of that particular lifeform. Cover estimates needed to be summed, since the total vegetation calculated in the field was based on the strata layer, not on the lifeform. Many species occur in all three strata layers (for example, ponderosa pine commonly occurred in the ground (small saplings), shrub (medium saplings), and tree layer). The percentage used to separate each lifeform type is based on FGDC criteria for NVCS formation classes and as interpreted by NatureServe (Grossman et al. 1998, Reid 2000 pers. comm.). Some relevés had greater than 25% total cover but less than 25% of tree, shrub or herbaceous cover. In those cases the relevé was assigned a formation class based on the dominant lifeform.

We used two different algorithms within PC-Ord to examine species association patterns in each matrix. A divisive method, Two-Way Indicator Species Analysis (TWINSpan), was used to review the relevé. TWINSpan produces a table that classifies sites and species. Initial species and relevé groupings were identified with this step. An agglomerate group averaging method, Unweighted Pair Group Method Using Arithmetic Mean (UPGMA), commonly known as cluster analysis, was next applied with the distance measure defined as Sorensen's coefficient (also known as the Czekanowski or Jaccard coefficient). Each relevé in the cluster analysis was labeled with preliminary alliance and association label based on iterative examination of the cluster analysis graphic output (a dendrogram), preliminary alliance descriptions for the western states (Reid et al. 1999) and the cover values for species in each relevé.

NatureServe reviewed the results of the data analysis, and the initial placement of relevés within associations and alliances. A number of vegetation types identified from the analysis represented associations already documented in the NVCS, and registered in NatureServe Explorer, an online encyclopedia of life (www.natureserve.org/explorer/). In some cases the vegetation types from the analysis did not correspond to existing associations in the NVCS (i.e. appeared to be new associations), and these were treated in three different ways according to the amount of information supporting them from the project. Those with a number of relevés (3-5 or more), or with fewer relevés but covering substantial mapping area were incorporated into the NVCS as

new plant associations. Those with some relevés (typically <3), but seemingly uncommon or of uncertain floristic composition, were designated as “provisional” plant associations in the NVC, and require additional sampling to fully understand their floristic and ecological characteristics. The last group of vegetation types was those represented by only one or two relevés, or that seemed essentially unique to SUCR. Until further inventory is completed, these should be thought of as “local” vegetation assemblages and we describe these throughout the report as local assemblages. A few relevés were classified only to the coarser alliance level.

A dichotomous key to the vegetation association/alliances as well as to the corresponding map classes (described below) was developed prior to the 2001 accuracy assessment field season. The key was used in the 2001 data collection for accuracy assessment. We made slight modifications before using the key in the second round of accuracy assessment data collection during the 2002 field season (Appendix E).

Vegetation map preparation

Four basic elements were used to create the SUCR vegetation map: 1) map class development, 2) aerial photography interpretation, 3) digital transfer, and 4) map validation. Following these steps, a formal accuracy assessment determined errors of omission and commission with the goal of achieving a minimum of 80% map accuracy.

Map class development

A relatively simple vegetation and land use classification was prepared to guide a preliminary aerial photointerpretation, completed by RSGIG in June 1999. CPRS ecologists also used this preliminary work to more fully examine the landscape and vegetation features of the project area during vegetation relevé sampling activities. So as not to bias field researchers, each polygon delineated was given a consecutive number, with attributes for each polygon number listed in a separate table.

Final SUCR map classes used for interpreting the aerial photographs were derived (1) from plant associations described by CPRS, (2) from the Anderson (1976) Level II land use classification system, and (3) from special requests by NPS staff. In some cases, one NVCS association corresponded to one mapping class; more often, because of difficulties in interpreting the CIR photographs, map classes described more than one plant association and were combined into mosaics or complexes of associations. For instance, we combined the two mountain meadow grassland associations (*Bouteloua gracilis* Herbaceous Vegetation and *Muhlenbergia montana* Herbaceous Vegetation) into a Montane Grassland map class. In some instances, NVCS association map classes provided less detail than could be photo-delineated. In these instances, we used modifiers to define and map additional modifiers of vegetation cover and understory species composition (e.g. Ponderosa Pine / Apache Plume Woodland was photo-delineated as >25% total vegetation cover, <25% total vegetation cover, and with >10% pinyon pine). This level of detail provided additional refinement in the map classes; however, only the map class and not the modifier was assessed in the accuracy assessment. The Anderson Level II land use classes included semi-natural vegetation and cultural types, i.e. roads, facilities, residential land, croplands and pastures, etc. Finally, special map classes were created for surficial geology or vegetation types recognized by NPS staff or the photointerpreters, but not part of the NVCS.

These special map classes include Cinder Sparse Mosaic, Lava Beds, and Rock Outcrop and Scree Shrubland.

Aerial photograph interpretation

As a preliminary step prior to actual interpretation, sheets of translucent (single-frosted) Mylar were taped over all of the 9" x 9" photos. The fiducial points (corner and side tics), flight line number, and photograph number were transferred from each photo onto the Mylar using a 0.5 mm lead pencil. Aerial photos and their overlays were backlit on a light table and examined for photographic signatures, using a stereoscope to identify the three-dimensional features. Where photographic signatures were unclear, the diapositives were examined in stereo to make a final determination of the appropriate polygon boundary and/or map class. Only the center portion of each aerial photograph was interpreted, to minimize the effects of edge distortion inherent to 9" x 9" stereo photographs.

The actual interpretation of aerial photographs involved three steps. First, all photos were interpreted into broad classes based solely on standard photointerpretation signature characteristics. These included: tone, texture, color, pattern, topographic position, size, and shadow. Second, field notes and observation points were used to assign the correct map classes. Finally, digital transfer specialists reviewed all of the interpreted photos for consistency and accuracy.

Digital transfer

An ArcInfo GIS database was built for SUCR using in-house protocols for creating vegetation GIS databases. The protocols consist of a shell of Arc Macro Language (AML) scripts and menus that automate the transfer process and insure that all spatial and attribute data are consistent and stored properly. The actual transfer of information from the interpreted aerial photographs to a digital, geo-referenced format involved two techniques. First the Mylar overlays were scanned and warped to fit the DOQQs; second, additional polygons were added using on-screen digitizing with the DOQQs as a background. Both techniques required a background image or base map, in this case the USGS black-and-white DOQQ's. These digital base maps were delivered to RSGIG in November 2000 and data transfer began immediately.

The scanning technique used for SUCR involved a multi-step process whereby the Mylar overlays with their interpreted line work were scanned into a digital image file (.tif file). The digital image file was then converted to a vector file, which was then geo-referenced to the DOQQ base maps. Essential to this process is to match the scale and position of features on the photographs (Mylars) with the scale and position of the same features on the DOQQs. This was accomplished by adjusting the scale of the photo Mylar between numbered control points (Figure 10). AMLs executed the actual manipulation of the vector files until the adjustment was considered a good fit by technicians. Any remaining land use polygons that were not included on the Mylars were transferred through on-screen digitizing. This process enters polygons directly into the GIS database by manually tracing digital lines (using a mouse) on a computer monitor screen with the DOQQ as a background image. Finally, the complete set of digitized line work files were linked into a single file, the polygon topology created, and polygon attribute information added to produce a completed digital coverage.

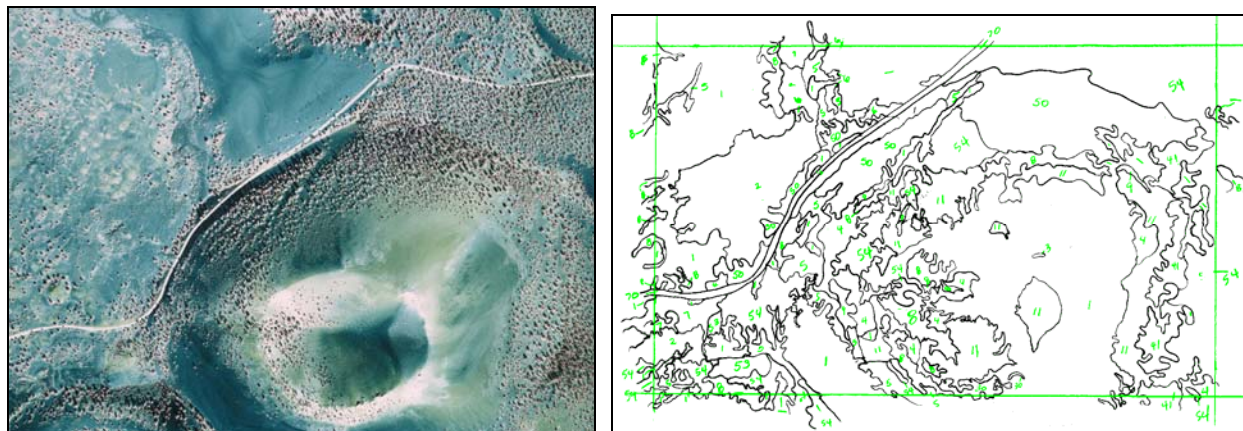


Figure 10. Aerial photo 4-7 and corresponding (scanned) Mylar overlay.

Map validation

A draft of the vegetation map was printed at the 1:12,000 scale and checked against the interpreted aerial photographs. As an internal accuracy check, we applied photointerpretive observation points over the vegetation map to determine if the map classes matched the field data.

Finally, field verification and revision of the draft map occurred prior to the accuracy assessment analysis. Field trips to validate the map were taken in January and May 2001. These trips included collecting additional photointerpretive observation points and ground-truthing aerial photograph signatures using landmarks and global positioning system (GPS) waypoints. We modified the map classes as a result of field verification and used the modified classes in the final photointerpretation. The final map revision was completed in September 2002.

Accuracy assessment

The CPRS field staff conducted the formal accuracy assessment of the SUCR vegetation map and vegetation association key. We conducted the field surveys in two phases, from August 1 to September 27, 2001 and from October 24 to November 8, 2002. Phase one of sampling was done with a preliminary vegetation map to allow for a majority of accuracy assessment reference points to be collected. Phase two was done with the final vegetation map to ensure that all reference points were collected. Data collection and analysis was done according to standard protocols developed by the USGS-NPS Vegetation Mapping Program, described in the Program Document, [Accuracy Assessment Procedures](#) (TNC and ERSI, 1994c) and “USGS-NPS Vegetation Mapping Program: 4.0 Sample Collection for Accuracy Assessment”, 4.4.2 second approach (<http://biology.usgs.gov/npsveg/aa/toc.html>, as of 11/12/2002), and were modified as needed (see below). As is common practice in measuring uncertainty in mapped classes, a sample of locations for each map class, referred to as reference points, were compared to a source of higher accuracy – ground truthing obtained by direct field observation.

Prior to selecting reference points, we checked topology and data structure of the coverage by running a check for node errors and label errors in the GIS dataset. We also dissolved the GIS dataset, removing polygon boundaries when adjoining polygons had the same value using GIS.

Reference point locations were then selected for each map class based on the total cover of each class in the mapping area, where map classes with more cover had more reference points assigned, and vice versa. The number of polygons to be sampled was determined by the number of polygons in each vegetation class and the total area of each vegetation class within the spatial vegetation dataset (Table 1). These standards were determined by USGS-NPS Vegetation Mapping Program criteria to ensure a 90% confidence level. Eight map classes were lumped together for accuracy assessment sampling design and analysis because several map classes were variations of the same plant association (map classes 8-10, 11-12 and 17-19). For example, map class 8 (montane grassland) was lumped together with map class 9 (montane grassland with rabbitbrush) and map class 10 (montane grassland occurring in Bonito Park), and these map classes were treated as a single map class. A table was compiled with vegetation types, the number of polygons and area in hectares for each vegetation type, and the number of polygons to be sampled (Table 1).

Table 1. USGS-NPS Vegetation Mapping Program criteria for sampling numbers for accuracy assessment

| Scenario | Description | Polygons in class | Area occupied by class | Recommended number of samples in class |
|----------|---|-------------------|------------------------|--|
| A | Abundant. Many polygons that cover a large area. | ≥ 30 | ≥ 50 ha | 30 |
| B | Relatively abundant. Class has few polygons that cover a large area. | < 30 | ≥ 50 ha | 20 |
| C | Relatively rare. Class has many polygons, but covers a small area. Many polygons are close to the MMU. | > 30 | < 50 ha | 20 |
| D | Rare. Class has few polygons, which may be widely distributed. Most or all polygons are close to the MMU. | $\geq 5, \leq 30$ | < 50 ha | 5 |
| E | Very rare. Class has too few polygons to permit sampling. Polygons are close to the MMU. | < 5 | < 50 ha | Visit all and confirm |

We assigned random numbers to polygons for each map class and selected the target number of polygons plus 5 to 10 extra in case targeted polygons could not be accessed. Of the 500 reference points initially chosen, 355 points were sampled in the field in the first phase and 131 in the second phase. We discarded some accuracy assessment points from the initial phase when multiple reference points occurred within a single polygon in the final vegetation map. In such cases, we selected the reference point that contained the largest area of the polygon assessed in the initial round of sampling as the point used for the final round of accuracy assessment.

In the first phase of sampling we used reference points from sampled polygons greater than the minimum mapping unit (MMU) of 0.5 hectares; however, if not enough samples of the map class were available from polygons greater than the MMU, we then sampled polygons less than the MMU. In polygons greater than the MMU, we assigned reference point coordinates randomly in the polygon excluding a 5-meter buffer from the polygon edge (Random Point Generator v.1.1, available at www.ESRI.com (ESRI 2002)). In polygons that were less than the MMU, the centroid of the polygon was used to locate the reference point so as to minimize edge effects from adjacent polygons. We gave the field team a list of UTM coordinates and a radius to survey around the points. In polygons greater than the MMU, a 0.5 hectare area (MMU) was surveyed. In polygons less than the MMU, a radius (less than the MMU) was provided to the field team to ensure that they would not survey in an adjacent polygon and they were to survey the entire radius prior to determining the map class. If the polygon size was less than a 10-meter radius (less than 0.03 hectares), then a polygon map was provided to the field team to orient them within the polygon and the whole polygon was to be surveyed.

In the second phase of sampling, polygons that were equal to or greater than MMU were given a 5-meter buffer from the outside polygon edge. Then a location within the polygon was chosen using a random point generator to add one point to each polygon. We selected the centroid as the sampling point in polygons less than the MMU. For each polygon to be sampled, the field team was provided a polygon map. In polygons greater than the MMU, the field team was to survey an area equivalent to the MMU prior to making a final determination of the map class. In polygons less than the MMU, the entire polygon was surveyed.

Data collection

The CPRS field team had a list of the UTM coordinates for each reference point, the area and perimeter of the polygon encompassing its location, and the shortest distance to an adjacent map class. In the first round of accuracy assessment sampling, polygon shapes were provided for small polygons (<0.5 hectares), which contained a distance scale and direction orientation. In the second round of accuracy assessment sampling, polygon shapes were provided for all polygons that were sampled. The field ecologists recorded accuracy assessment observations on a field form (Appendix D), including the following: the vegetation association/map class within the radius of the reference point, confidence in the decision according to the descriptions of the association/map classes in the field key (using the following four categories: exact, good (some problems), poor, or none that fit), explanation of confidence if less than exact, UTM coordinates (easting, northing), altitude, and GPS error (using the Garmin 45XL, Garmin Corporation, 1996).

During the fieldwork, ongoing discussions between the field ecologists and CPRS plant ecologists allowed for refinement of the plant association/map class key, as well as some of the vegetation classifications. These changes were implemented in the key and may have influenced

the interpretation of the association/map class concepts between the first and second round of sampling. We accounted for these changes during the accuracy assessment analysis described below.

Accuracy assessment analysis

Accuracy assessment statistics were prepared by comparing the map class observed in the field (accuracy assessment observation or reference data) with the map class mapped at the same location on the final vegetation map (map class data). We made these comparisons using both standard accuracy assessment analysis identified as part of the USGS/NPS Vegetation Mapping Program (<http://biology.usgs.gov/npsveg/aa/toc.html>) and a modified ‘fuzzy set’ accuracy assessment analysis (Klopfer et al. 2002). Accuracy assessed observations were overlain onto the final vegetation map to determine the corresponding map class for each location except for those places that were remotely assessed in 2002.

For each standard and fuzzy set comparison, a contingency table was developed to compare the reference data with the map class data. The contingency table lists reference data values in the columns and map class values in the rows. The number of each reference data and map class pair for all sampling locations is located at each row/column intersection in the matrix (see Table 7 for an example). Correct mappings are indicated on the table where the row and column values are the same and typically occur on the diagonal on the matrix (yellow highlight on Table 7). The contingency table is used to calculate a variety of statistics describing the map performance: omission accuracy (also known as producer’s accuracy), commission accuracy (also known as user’s accuracy), the overall accuracy, and the Kappa index.

Initial analysis revealed a low overall accuracy and therefore we examined the errors associated with each observation using a modified ‘fuzzy set’ analysis to rank the type of error (Klopfer et al. 2002, Falzarano and Thomas In Press). In this assessment, we use five criteria (exact match, acceptable error, understandable error, vague similarity, and complete error) to assess the fit between the reference data and map class sampling location (Table 2) (Klopfer et al. 2002). We included only criteria 5, 4, and 3 in our analysis, since criteria 2 and 1 did not provide any additional information to our accuracy assessment analysis.

Table 2. Definitions used in the 'fuzzy set' analysis classifications.

| Criteria | Descriptions |
|----------|---|
| 5 | Exact Match: The reference data is an exact match to the map class. |
| 4 | Acceptable Error: If any of the following criteria were met than the case was considered acceptable error: 1) The reference data is the same as a map class in the nearest adjacent polygon and is within 35 meters of that polygon (distance chosen based on project specific considerations), 2) The reference data is in a 2001 polygon that became an inclusion below the MMU in 2002 and had similar floristic and structural composition of the larger 2002 polygon, 3) An alternative correct reference class was described in the field, or 4) The reference class described using the 2001 plant association field key was an alternative map class described using the 2002 map class field key. |
| 3 | Understandable Error: The map class has similar structural composition and species dominance. |
| 2 | Vague Similarity: The map class has a similar formation type, but not similar species composition. |
| 1 | Complete Error: No similarity in the species or structural composition. |

A contingency table was created for three criteria: 1) standard or exact match—a correct map class was considered to occur where there was exact match between the reference data and map class data, 2) acceptable error—a correct label was represented by exact (criteria 5) and acceptable (criteria 4) matches between reference data and map class data, and 3) understandable error—a correct label was represented by exact (criteria 5), acceptable (criteria 4) and understandable (criteria 3) matches between reference data and map class data. We would like to point out that the standard accuracy assessment is the same criteria as an exact match in the modified fuzzy set analysis.

An example of acceptable error is the case of a field observation of Cinder Sparse Mosaic mapped as Lava Beds. In this example, the field observation is 25 meters from the nearest polygon, has an error of 15 meters, and that polygon is labeled Lava Bed. We have categorized the classification relevé as acceptable since it is in close proximity to the correct map class and we believe that the apparent misclassification may be a locational error either on the map or in the field rather than a photointerpretation misclassification.

The 2001 vegetation map was developed to vegetation associations (1:1 relationship), however in 2002 the vegetation map was developed to contain aggregates of associations. Concurrently the field key in 2001 was strictly to associations and did not reflect the 2002 map class descriptions. As a result, interpretation of the accuracy of a 2001 classification relevé might be more restrictive than in 2002. For example, consider a classification relevé in 2001 of Apache Plume / Cinder Sparse Vegetation on lava. In 2002 any vegetation association occurring in a lava bed outcrop was defined as Lava Bed Sparse Vegetation, and the map class is Lava Bed Sparse Vegetation. In this case the 2001 observation was acceptable according to the final definitions of map classes.

Another case for acceptable error occurred in the switch between the 2001 and 2002 map. For example, a classification relevé of Montane Grassland was made in 2001 and its location was in a small (10 meter radius) polygon based on the preliminary map. However, on the final map, the sampling location for this classification relevé was found to now be included in a larger polygon (7.5 hectares) labeled Ponderosa Pine / Montane Grass Mosaic. The notes for the original observation described the field situation as small grassland around scattered ponderosa pine. In this case, where the scale of consideration changed, the classification relevé was considered to be an acceptable match to the final map class.

An example of understandable error is if the field observation has a similar species composition and structure as the map class assigned to the polygon containing the observation. For example, Ponderosa Pine / Invasive Herbaceous Vegetation as the reference label and Ponderosa Pine / Montane Grass Mosaic as the map class have the same structure and species composition, except for the understory community. In this case, it is likely that it was difficult for the photointerpreters to delineate the understory community.

Vaguely similar would include the case where the classification relevé (Pinyon Pine - Utah Juniper / Blue Grama Woodland) structure is similar to the map class (Ponderosa Pine / Apache Plume Woodland), however the species composition is not similar. An example of complete error is when the reference label (Ponderosa Pine Invasive Herbaceous Vegetation) has no similarity with the map class (Apache Plume / Cinder Sparse Vegetation) in terms of structure or species composition.

Where the field observation was determined to ‘fit’ the map class for a particular criteria, the field observation was ‘reassigned’ to the map class for the purposes of constructing the error matrix. Hence the diagonals on the error matrix show the sum of all accuracy assessment observation/map class pairs that were matches under the particular criteria being applied.

Overall total accuracy for each contingency table criteria as described above (standard analysis, acceptable error, and understandable error) was calculated by dividing the total number of correctly classified reference data points by the total number of reference data points. Individual map class accuracies were also assessed for each of the criteria described above. To calculate the probability that a reference data observation has been correctly classified (producer’s accuracy or omission error), the number of reference data points correctly classified is divided by the total number of reference data points in that map class. To calculate the probability that the mapped vegetation associations represent the associations actually found on the ground (user’s accuracy or commission error), the number of correctly identified reference samples was divided by the total number of samples classified or mapped to that vegetation association.

Equations to calculate statistics for each criteria described occur in the program document, Accuracy Assessment Procedures (<http://biology.usgs.gov/npsveg/aa/toc.html>) and TNC and ERSI (1994c). Two-tailed, 90% confidence intervals for the binomial distribution were also calculated using JMP statistical software (SAS Institute 1989-2000) using Score Confidence Interval Tables. Score Confidence Interval Tables are known to have better coverage probabilities with smaller sample sizes (Agresti and Coull 1998). To account for correct

classifications due to chance, a Kappa index (Foody, 1992; TNC-ERSI, 1994c) was calculated also using JMP statistical software.

4. RESULTS

Field surveys

We observed forty-six observation photointerpretation sites and 114 classification relevés, including 2 laser obtained relevés (Figure 11). At each classification relevé we took two photos. Information recorded for each relevé and relevé photos are on the project CD (see Appendix A).

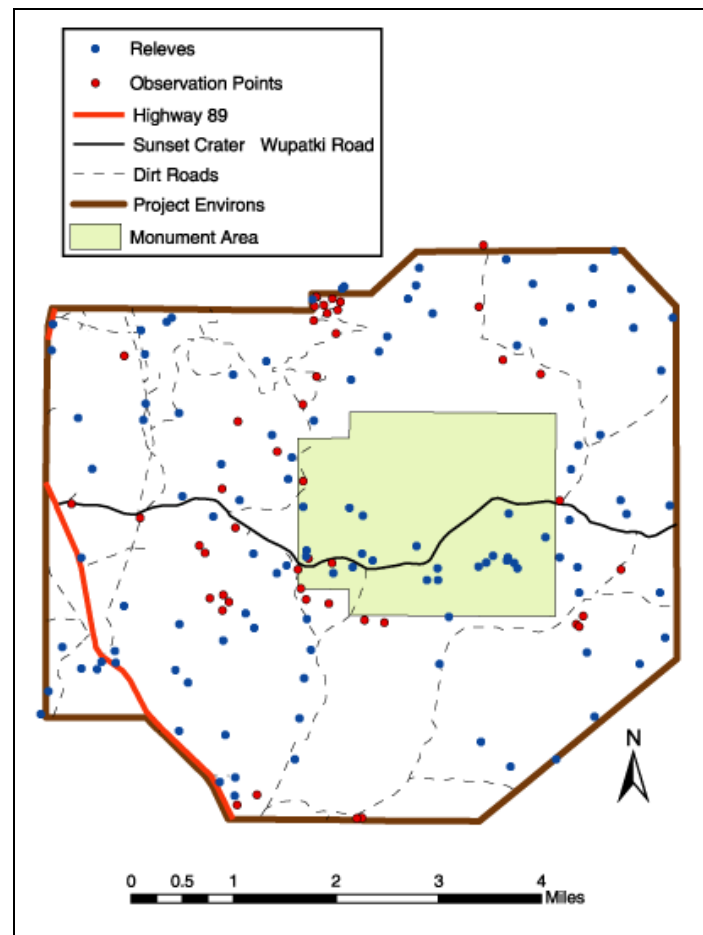


Figure 11. Location of photointerpretation observation and classification relevés.

Vegetation classification

The NVCS classification resulted in a total of 12 alliances, 15 associations, and five monument specific local assemblages (Table 3). Full descriptions of the SUCR vegetation associations and provisional associations are located in Appendix F. A listing of all species identified during the course of this study can be found in Appendix G. Five local assemblages were identified as possibly being unique to SUCR; these assemblages need further sampling on the Colorado Plateau to determine if they represent local vegetation types unique to SUCR or if they are found across the landscape. Four alliances and seven associations are newly described in the NVCS. The alliances, as grouped by formation, consist of two forest, three woodland, one shrubland,

four herbaceous, and three sparse alliances. The associations consist of two forest, six woodland, four herbaceous, and three sparse classes. The plant associations, local associations, Anderson land-use classes, and geologic exposures are related to the aerial photointerpretation map classes and are listed in Appendix H. A field key to both the map classes and alliance/association classification is listed in Appendix E.

Table 3. Sunset Crater Volcano National Monument NVCS assignments

| Formation Class | Assignment | NVCS Alliance | NVCS Association | Relevé # |
|-----------------|------------------------------|---|--|--|
| Forest | Association | <i>PINUS EDULIS</i> FOREST ALLIANCE | <i>Pinus edulis</i> / Sparse Understory Forest | SC-091 |
| | Alliance | <i>PSEUDOTSUGA MENZIESII</i> FOREST ALLIANCE | No Association | SC-078 |
| | Association | <i>PSEUDOTSUGA MENZIESII</i> FOREST ALLIANCE | <i>Pseudotsuga menziesii</i> / <i>Muhlenbergia montana</i> Forest | SC-079 |
| Woodland | Association | <i>PINUS EDULIS</i> - (<i>JUNIPERUS SPP.</i>) WOODLAND ALLIANCE | <i>Pinus edulis</i> - (<i>Juniperus osteosperma</i>) / <i>Bouteloua gracilis</i> Woodland | SC-008, SC-012, SC-036, SC-037, SC-092, SC-096, SC-102 |
| | Alliance | <i>PINUS FLEXILIS</i> WOODLAND ALLIANCE | No Association | SC-075 |
| | New Association | <i>PINUS PONDEROSA</i> WOODLAND ALLIANCE | <i>Pinus ponderosa</i> / <i>Andropogon hallii</i> Woodland | SC-105 |
| | Association | <i>PINUS PONDEROSA</i> WOODLAND ALLIANCE | <i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland | SC-004, SC-005, SC-013, SC-025 |
| | New Association | <i>PINUS PONDEROSA</i> WOODLAND ALLIANCE | <i>Pinus ponderosa</i> / <i>Fallugia paradoxa</i> Woodland | SC-015, SC-019, SC-024, SC-042, SC-044, SC-045, SC-049, SC-064, SC-065, SC-066, SC-069, SC-076, SC-077, SC-081, SC-085, SC-087, SC-088, SC-089, SC-090, SC-095, SC-100, SC-101, SC-103, SC-108, SC-109, SC-110, SC-112 |
| | Association | <i>PINUS PONDEROSA</i> WOODLAND ALLIANCE | <i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland | SC-001, SC-010, SC-026, SC-027, SC-031, SC-032, SC-034, SC-035, SC-041, SC-052, SC-055, SC-059 |
| | New Association | <i>PINUS PONDEROSA</i> WOODLAND ALLIANCE | <i>Pinus ponderosa</i> / Cinder Woodland | SC-006, SC-009, SC-016, SC-017, SC-018, SC-022, SC-029, SC-038, SC-039, SC-040, SC-051, SC-054, SC-058, SC-061, SC-062, SC-063, SC-071, SC-073, SC-094, SC-104, SC-106, SC-111 |
| | Local Assemblage | <i>POPULUS TREMULOIDES</i> WOODLAND ALLIANCE | <i>Populus tremuloides</i> / Cinder Woodland | SC-093 |
| | New Alliance and Association | <i>FALLUGIA PARADOXA</i> SHRUBLAND ALLIANCE | <i>Fallugia paradoxa</i> - (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Shrubland | SC-014, SC-048, SC-083, SC-097 |
| | Local Assemblage | undefined | <i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> – (<i>Holodiscus dumosus</i>) Scree Shrubland | SC-067, SC-074, SC-080 |
| | Local Assemblage | undefined | <i>Pinus ponderosa</i> / <i>Rhus trilobata</i> Shrubland | SC-033 |

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| Formation Class | Assignment | NVCS Alliance | NVCS Association | Relevé # |
|------------------------|------------------------------|---|--|---|
| Herbaceous | Association | <i>ANDROPOGON HALLII</i> HERBACEOUS ALLIANCE | <i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation | SC-047, SC-050 |
| | Association | <i>BOUTELOUA GRACILIS</i> HERBACEOUS ALLIANCE | <i>Bouteloua gracilis</i> Herbaceous Vegetation | SC-002, SC-003, SC-007, SC-011, SC-053 |
| | Association | <i>MUHLENBERGIA MONTANA</i> HERBACEOUS ALLIANCE | <i>Muhlenbergia montana</i> Herbaceous Vegetation | SC-068 |
| | New Alliance and Association | <i>PASCOPYRUM SMITHII</i> HERBACEOUS ALLIANCE | <i>Pascopyrum smithii</i> Herbaceous Vegetation | SC-028, SC-043 |
| | Local Assemblage | undefined | <i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation | SC-056, SC-057, SC-060, SC-070 |
| Sparse | Local Assemblage | undefined | <i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation | SC-099 |
| | New Alliance and Association | <i>ERIOGONUM CORYMBOSUM</i> SPARSELY VEGETATED ALLIANCE | <i>Eriogonum corymbosum</i> Cinder Sparse Vegetation | SC-046 |
| | New Alliance and Association | AA LAVA BED SPARSELY VEGETATED ALLIANCE | <i>Pinus ponderosa</i> -(<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> -(<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation | SC-021, SC-023, SC-072, SC-113, SC-114 |

Unvegetated to sparsely vegetated cinder, lava beds, and rock outcrops are very common in the project area. Although, they are considered a geologic type and are not classified to a NVCS association, they are prevalent and comprise approximately 16% (3,050 acres) of the total area mapped. In some areas lichen cover is high on the lava rocks, and annual vegetation communities, although sparse, are consistent. Annual species and small herbaceous perennial species often include phacelia (*Phacelia* sp.), Newberry's twinpod (*Physaria newberryi*), and blazingstar (*Mentzelia* sp.). Sparsely vegetated shrublands often occur on cinder and lava beds and are most often dominated by wild buckwheat (*Eriogonum corymbosum*) and Apache plume (*Fallugia paradoxa*). Sparsely vegetated areas also often occur as islands of vegetation in lava outcrops. These outcrops may include isolated trees such as ponderosa pine (*Pinus ponderosa*) and quaking aspen (*Populus tremuloides*) as well as groups of shrubs including Apache plume and ocean spray (*Holodiscus dumosus*).

Forests only occur at the highest elevations of the project area and cover less than 1% (72 acres) of the project area. Only one map class (Douglas-fir Forest) is mapped as a forest type. Douglas-fir (*Pseudotsuga menziesii*) can form dense stands on the slopes of O'Leary Peak. Due to high density (crown cover) in some pinyon pine stands, these areas are also classified as forest alliances rather than woodland alliances. However, these dense stands were not mapped separately from the woodland types and were aggregated into the Pinyon Pine – Utah Juniper / Blue Grama Woodland map class.

Woodlands are the predominant vegetation type, covering approximately 60% of the project area (12,548 acres) and occur on all landforms including flats, slopes, hills, drainages, and ridges. Seventy-five of the total 114 relevés sampled were classified as woodlands (Table 3). This includes four alliances and seven associations among the alliances. Three of the associations are newly described. Ponderosa pine woodlands occur most frequently in the park and are found on nearly every landform, except the driest south-facing slopes and at the highest elevations.

Ponderosa pine most often occurs in pure stands; however, it can intermix in areas of high elevation with Douglas-fir or limber pine (*Pinus flexilis*). In drier areas, on south-facing and steep slopes, ponderosa pine can also co-occur with pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*). Pinyon pine and Utah juniper persist on the dry south-facing flanks of cinder cones and their rims, mountain toeslopes, and lower elevation dry flats. Quaking aspen occurs only in very small stands and patches within the lava beds, in small areas along the lava beds, and in small stands on cinder beds.

Shrublands cover less than 1% (11 acres) of the project area and occur mainly in small patches. Only one map class (Rock Outcrop and Scree Shrubland) was classified as a shrubland type. All of the relevés in this map class were classified as local associations, with unique species composition, and did not have enough data to support classification under the NVCS shrubland formation class. Two of the sparse vegetation map classes are sparse shrublands. Shrubs also often occur in small patches under tree canopy. Shrubs can also co-dominate with grasses in open meadows. Apache plume occurs most frequently in the park and is often associated with ponderosa pine trees. It also occurs in sparse cinder open areas and in lava beds. Other shrubs are also common to these geologic features and include species such as rabbitbrush (*Ericameria nauseosa*), three-leaved sumac (*Rhus trilobata*), ocean spray, pericome (*Pericome caudata*), brickellbush (*Brickellia californica*), and wax currant (*Ribes cereum*). These shrubs also occur on a variety of substrates and landforms.

Grasslands often occur in small patches in or near ponderosa pine woodlands and covers 9% (1,708 acres) of the project area. Blue grama (*Bouteloua gracilis*) and mountain muhly (*Muhlenbergia montana*) are the two most dominant species in these grassland meadow areas. Blue grama is most associated with the lower to mid-elevation areas of the project area and is probably the most common grass species. Blue grama occurs in Bonito Park and in some areas is co-dominant with rabbitbrush. Mountain muhly dominates the upper elevation meadows and often co-dominates with blue grama at mid-elevations. Sand bluestem (*Andropogon hallii*) is a bunchgrass that occurs mostly in sparse patches in the eastern section of the project area and often occurs with ponderosa pine. Western wheatgrass (*Pascopyrum smithii*) is a common understory species in the recently burned areas northwest of the project area. Western wheatgrass was probably used in seed mixes for re-seeding efforts and was found only in the burned areas. Four percent (760 acres) of these grasslands contain recently disturbed areas with evidence of thinning and burning of ponderosa pine. In these areas introduced annual grasses, particularly cheatgrass (*Bromus tectorum*), native forbs such as meadow-rue (*Thalictrum fendleri*) and Carruth's sagewort (*Artemisia caruthii*) and the invasive non-native toadflax (*Linaria dalmatica* ssp. *dalmatica*) and mullein (*Verbascum thapsus*) are common.

Vegetation map classes

A total of 26 map classes, including 5 modifiers, were recognized in the SUCR vegetation map (Table 4). These map classes consist of 21 vegetation classes, including 5 modifiers, and 6 Anderson Level II (Anderson et al. 1976) land-use classes.

Table 4. SUCR Map classes and their NVCS components

| Map Code | Map Class | Map Class NVCS Name |
|----------|---|---|
| 1 | Cinder Sparse Mosaic | none (Land Cover Class) |
| 2 | Lava Beds | none (Land Cover Class) |
| 3 | Rock Outcrop and Scree Shrubland | <i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> – (<i>Holodiscus dumosus</i>) Scree Shrubland (Local Assemblage), <i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation (Local Assemblage) |
| 4 | Wild Buckwheat - Sand Bluestem Sparse Vegetation | <i>Eriogonum corymbosum</i> - <i>Andropogon hallii</i> Sparse Vegetation |
| 5 | Apache Plume / Cinder Sparse Vegetation | <i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation |
| 6 | Lava Bed Sparse Vegetation | <i>Pinus ponderosa</i> - (<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> - (<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation |
| 7 | Sand Bluestem Herbaceous Vegetation | <i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation |
| 8-10 | Montane Grassland (Rabbitbrush, Bonito Park) | <i>Bouteloua gracilis</i> Herbaceous Vegetation, <i>Muhlenbergia montana</i> Herbaceous Vegetation |
| 11-12 | Pinyon Pine - Utah Juniper / Blue Grama Woodland (Sparse) | <i>Pinus edulis</i> - (<i>Juniperus osteosperma</i>) / <i>Bouteloua gracilis</i> Woodland, <i>Pinus edulis</i> / Sparse Understory Forest |
| 13 | Limber Pine Woodland | <i>Pinus flexilis</i> Woodland Alliance |
| 14 | Ponderosa Pine / Cinder Woodland | <i>Pinus ponderosa</i> / Cinder Woodland |
| 15 | Ponderosa Pine / Montane Grass Mosaic | <i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland, <i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland |
| 16 | Ponderosa Pine Invasive Herbaceous Vegetation | <i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation (Local Assemblage), <i>Pascopyrum smithii</i> Herbaceous Vegetation |
| 17-19 | Ponderosa Pine / Apache Plume Woodland (Pinyon, Sparse) | <i>Pinus ponderosa</i> / <i>Fallugia paradoxa</i> Woodland |
| 20 | Ponderosa Pine / Sand Bluestem Woodland | <i>Pinus ponderosa</i> / <i>Andropogon hallii</i> Woodland |
| 21 | Douglas-fir Forest | <i>Pseudotsuga menziesii</i> / <i>Muhlenbergia montana</i> Forest, <i>Pseudotsuga menziesii</i> Forest Alliance |
| 22 | Transportation, Communications, and Utilities | - none (Anderson Land Use class) |
| 23 | Facilities | - none (Anderson Land Use class) |
| 24 | Residential Land | - none (Anderson Land Use class) |
| 25 | Reservoirs and Trick Tanks | - none (Anderson Land Use class) |
| 26 | Strip Mines, Quarries, and Gravel Pits | - none (Anderson Land Use class) |
| 27 | Croplands and Pastures | - none (Anderson Land Use class) |

Three of the map classes; Montane Grassland (map codes 8-10), Pinyon Pine – Utah Juniper / Blue Grama Woodland (map codes 11-12), and Ponderosa Pine / Apache Plume Woodland (map codes 17-19); were further subdivided by two or three modifiers. These modifiers represent variations of the NVCS vegetation association that were easily mapped and were useful to resource management (for example, map class Montane Grassland is mapped as pure Montane Grassland (map code 8), Montane Grassland with a greater than 10% rabbitbrush (*Ericameria nauseosa*) (map code 9), and Montane Grassland that occurs in Bonito Park (map code 10). The final map classes were determined in a series of meetings among NPS, USGS, and BOR participants using the information obtained from photointerpretation observations, classification

relevés, and preliminary photointerpretation. While the ideal situation is to have each map class correspond to one NVCS plant association, we had to deviate from this in cases where NVCS associations could not be discerned from the aerial photography, such as some of the canopied woodland types. Also, some map classes did not directly correspond to NVCS associations but were included as “park specials” to aid with SUCR’s management needs.

A few of the map classes occurred consistently in patches smaller than the minimum mapping unit (0.5 hectares), particularly Rock Outcrop and Scree Shrubland (map code 3). Because of the importance of these classes for wildlife habitat and monument management priorities, a decision was made to map them where possible regardless of size.

The map classes for SUCR can be described by four categories:

1. NVCS associations represented by a unique photosignature and topographic position (one map class to one plant association)
2. Multiple NVCS associations that together are represented by a unique signature (one map class represents a mosaic of several related plant associations)
3. Stands of vegetation that were not addressed by the NVCS but are seen as management concerns for SUCR and could be recognized on the aerial photography (“park special” map classes)
4. Geologic formations/exposures and land-use classes that are not described within the NVCS

Each map class for SUCR can be crosswalked to their NVCS association using the aggregations described below:

One Map Class to One Plant Association

These map classes were developed by directly translating a NVCS vegetation association into a map class onto the aerial photography.

Map Map Class

Code NVCS Plant Association

- | | |
|---|---|
| 4 | Wild Buckwheat - Sand Bluestem Sparse Vegetation <i>Eriogonum corymbosum</i> - <i>Andropogon hallii</i> Sparse Vegetation |
| 5 | Apache Plume / Cinder Sparse Vegetation <i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation |
| 6 | Lava Bed Sparse Vegetation <i>Pinus ponderosa</i> -(<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> -(<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation |
| 7 | Sand Bluestem Herbaceous Vegetation <i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation |

- 13 Limber Pine Woodland
Pinus flexilis Woodland Alliance
- 14 Ponderosa Pine / Cinder Woodland
Pinus ponderosa / Cinder Woodland Alliance
- 17-19 Ponderosa Pine / Apache Plume Woodland (Pinyon, Sparse)
Pinus ponderosa / *Fallugia paradoxa* Woodland
- 20 Ponderosa Pine / Sand Bluestem Woodland
Pinus ponderosa / *Andropogon hallii* Woodland

Multiple Associations-to-One Map Class

NVCS associations and local assemblages identified in the aerial photography were too intermixed to identify as unique photosignatures. NVCS associations were aggregated with ecologically similar NVCS associations to form mosaics.

| Map Code | Map Class NVCS Plant Association/Alliance |
|----------|--|
| 3 | Rock Outcrop and Scree Shrubland <i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> –(<i>Holodiscus dumosus</i>) Scree Shrubland (Local Assemblage) <i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation (Local Assemblage) |
| 5 | Apache Plume / Cinder Sparse Vegetation <i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation |
| 8-10 | Montane Grassland (Rabbitbrush, Bonito Park) <i>Bouteloua gracilis</i> Herbaceous Vegetation <i>Muhlenbergia montana</i> Herbaceous Vegetation |
| 11-12 | Pinyon Pine - Utah Juniper / Blue Grama Woodland (Sparse) <i>Pinus edulis</i> - (<i>Juniperus osteosperma</i>) / <i>Bouteloua gracilis</i> Woodland <i>Pinus edulis</i> / Sparse Understory Forest |
| 15 | Ponderosa Pine / Montane Grass Mosaic <i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland <i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland |
| 16 | Ponderosa Pine Invasive Herbaceous Vegetation <i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation (Local Assemblage) <i>Pascopyrum smithii</i> Herbaceous Vegetation |

- 21 Douglas-fir Forest
Pseudotsuga menziesii / *Muhlenbergia montana* Forest
Pseudotsuga menziesii Forest Alliance

Park Special Map Classes

Only one map class at SUCR is considered a park special. This map class was developed based on local vegetation assemblages identified in the classification relevés.

| Map Code | Map Class |
|----------|------------------------|
| | NVCS Plant Association |

- 3 Rock Outcrop and Scree Shrubland
Fallugia paradoxa – *Brickellia grandiflora* –(*Holodiscus dumosus*) Scree Shrubland (Local Assemblage)
Ericameria nauseosa - *Pericome caudata* Rock Outcrop Sparse Vegetation (Local Assemblage)

Aerial photograph interpretation

The SUCR project area is represented mostly by sparse vegetation growing from cinder beds, lava flows, and woodlands growing from a number of substrates. The lava flows contain some sparse woodland and shrubland types, but are mostly barren or support a unique flora of lichens and mosses. Cinder beds are both black and red in color, but regardless of color, support sparse forblands, grasslands, and woodlands. Downwind from the pumice mines and near areas subjected to OHV use, the cinder beds are covered by a heavy dust layer.

Interpretation of the late fall, color-infrared aerial photographs for SUCR relied heavily on substrate and landscape position to help determine classes for vegetation polygons since the usual cues of color, shape, and texture were not distinctive for many of the map classes. Long tree shadows were present in the forest and woodland landscapes, partially or completely obscuring the understory. Because the aerial photographs were acquired in October when most of the grass species were dormant, color could not be used to distinguish among the different grassland types. An illustrated guide to the map classes, including a brief description of each map class, its distribution on the landscape, and its photosignature characteristics appears in Appendix H.

GIS database and maps

The SUCR GIS database consists of 11 coverages, 1 basemap imagery file, and associated metadata in ArcInfo format and is archived on a CD (Appendix A) accompanying this report. The coverages and imagery are:

- Accuracy assessment observation points.
- Aspen map. Small photointerpreted aspen (*Populus tremuloides*) patches.
- Classification relevé points.

- d. DOQQ and USGS Quad maps for Sunset Crater, Wupatki, and Walnut Canyon National Monuments.
- e. DOQQ basemap imagery (MrSid images) for SUCR.
- f. Flightline boundary for Sunset Crater, Wupatki, and Walnut Canyon National Monuments.
- g. OHV map. Photointerpreted tracks of off-highway vehicle use.
- h. SUCR park boundary.
- i. Photointerpretative observation points.
- j. Project boundary.
- k. Vegetation map clipped to the National Monument boundary.
- l. Vegetation map for the entire project area. This main product coverage consists of a single Arc Info coverage, developed from a mosaic of 46 aerial photographs (Figure 12), with 1,205 classified polygons covering a total area of approximately 7,590 hectares (18,750 acres). Table 5 shows the total number of polygons and hectares per map class in the project area.

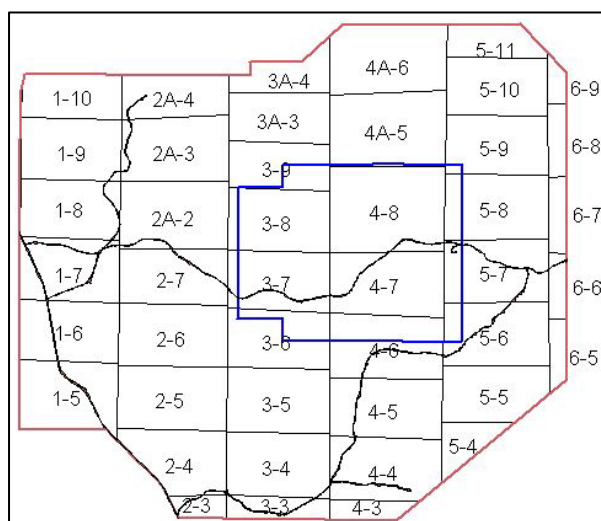


Figure 12. Aerial photograph boundaries

A readme file (Appendix A) further describes these coverages.

A hard copy map was created of the vegetation coverage with a legend identifying the color of each map class. For clarity, the map code was printed only on polygons with an area greater than 5000 m² (0.5 hectare). The hard copy map is presented in a folder sleeve (Appendix I).

Table 5. Map class occurrence in Sunset Crater Volcano National Monument and the environs.

| Map Code | Map Class Common Names | Monument | | Environs | |
|----------|---|------------|--------------|--------------|--------------|
| | | Polygons | Hectares | Polygons | Hectares |
| | | | | | |
| 1 | Cinder Sparse Mosaic | 51 | 379 | 204 | 620 |
| 2 | Lava Beds | 10 | 221 | 2 | 10 |
| 3 | Rock Outcrop and Scree Shrubland | 2 | 0.1 | 11 | 4 |
| 4 | Wild Buckwheat – Sand Bluestem Sparse Vegetation | 11 | 15 | 23 | 32 |
| 5 | Apache Plume / Cinder Sparse Vegetation | 33 | 27 | 159 | 202 |
| 6 | Lava Bed Sparse Vegetation | 50 | 79 | 8 | 5 |
| 7 | Sand Bluestem Herbaceous Vegetation | 10 | 32 | 2 | 1 |
| 8 | Montane Grassland | | | 104 | 148 |
| 9 | Montane Grassland (Rabbitbrush) | | | 51 | 100 |
| 10 | Montane Grassland (Bonito Park) | | | 1 | 101 |
| 11 | Pinyon Pine – Utah Juniper / Blue Grama Woodland | 5 | 2 | 51 | 361 |
| 12 | Pinyon Pine – Utah Juniper / Blue Grama Woodland (Sparse) | | | 8 | 33 |
| 13 | Limber Pine Woodland | | | 9 | 13 |
| 14 | Ponderosa Pine / Cinder Woodland | 26 | 93 | 61 | 1038 |
| 15 | Ponderosa Pine / Montane Grass Mosaic | 1 | 3 | 69 | 1223 |
| 16 | Ponderosa Pine Invasive Herbaceous Vegetation | | | 19 | 309 |
| 17 | Ponderosa Pine / Apache Plume Woodland (Sparse) | 51 | 115 | 127 | 224 |
| 18 | Ponderosa Pine / Apache Plume Woodland | 18 | 238 | 41 | 1649 |
| 19 | Ponderosa Pine / Apache Plume Woodland (Pinyon) | 1 | 1 | 19 | 66 |
| 20 | Ponderosa Pine / Sand Bluestem Woodland | 4 | 15 | 3 | 5 |
| 21 | Douglas-fir Forest | | | 7 | 29 |
| 22 | Transportation, Communications, and Utilities | 1 | 7 | 2 | 56 |
| 23 | Facilities | 1 | 1 | 3 | 7 |
| 24 | Residential Land | | | 10 | 3 |
| 25 | Reservoirs and Trick Tanks | | | 2 | 1 |
| 26 | Strip Mines, Quarries, and Gravel Pits | | | 9 | 65 |
| 27 | Croplands and Pastures | | | 3 | 57 |
| | Total | 275 | 1,227 | 1,008 | 6,361 |

Accuracy assessment

In the 2001 sampling season, 204 accuracy assessment observations were included in the reference data out of the total 334 accuracy assessment observations that were collected. One hundred and thirty-one accuracy assessment observations were eliminated since they represented duplicate observations in polygons in the final vegetation map. In these duplicate cases, the field observation that assessed the largest area of the polygon was selected as the field observation data to be used in the accuracy assessment analysis. For 2002, 130 additional field observations were added to the accuracy assessment reference data making a combined total of 334 reference points for the final accuracy assessment analysis (Figure 13). The final number of reference points analyzed for each map class was representative of the total area of each map class except for map classes with high percentage of occurrence on private land (i.e. land use classes). In these cases, the number of reference points sampled was less than the number suggested for the accuracy assessment analysis.

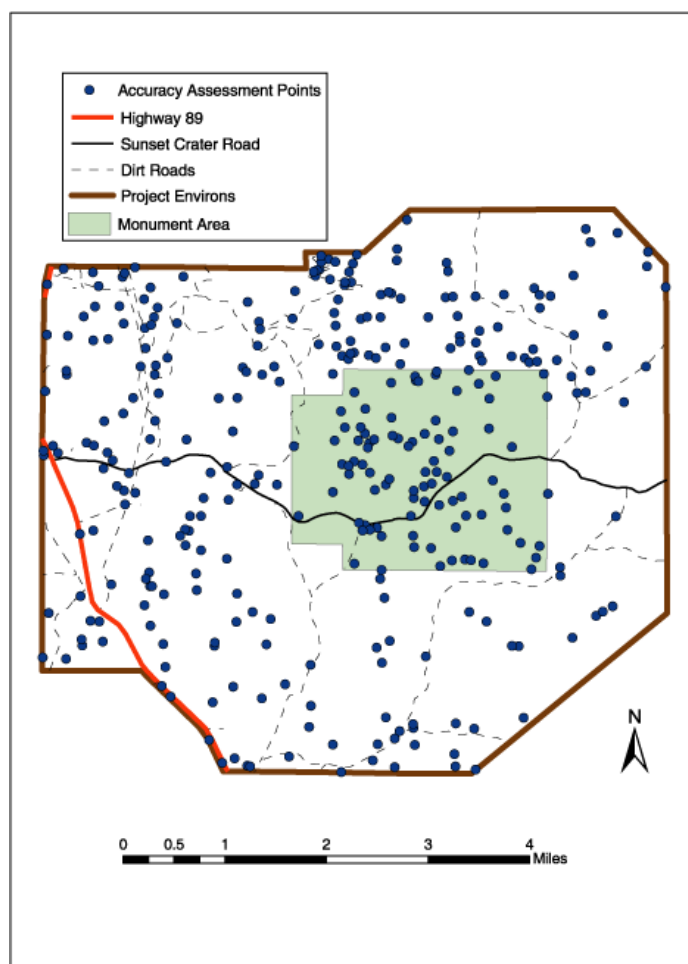


Figure 13. Location of accuracy assessment field observations for the 2001 and 2002 combined reference data set.

Evaluation of the performance of each map class can provide insight on map error. For each map class we report the criteria at which the class was assessed to meet the standard of 80% or greater for commission and omission accuracy (Table 6).

Standard analysis of map accuracy (criteria 5, exact criteria) suggested that overall accuracy was low, 53.9% (90% confidence interval of 43.7% to 64.1% and a Kappa index of 50.1%, Table 7). For criteria 4, acceptable error, accuracy of the map is 70.3% (90% confidence interval of 69.0% and 84.0%) and Kappa index of 68.0% (Table 8). Criteria 3, understandable error, accuracy is 86.8% (90% confidence interval of 84.1% and 95.4%) and a Kappa index of 85.8% (Table 9). Omission and commission accuracies for each individual map class, including two-tailed, 90% confidence intervals, are also shown for each criteria in each contingency table.

Table 6. Map class performance.

| Map Code | Map Class | Commission Accuracy (Criteria and %) | Omission Accuracy (Criteria and %) | Comments |
|----------|--|--------------------------------------|------------------------------------|--|
| 1 | Cinder Sparse Mosaic | Acceptable 80% | Understandable 87% | This type is considered adequate as mapped. |
| 2 | Lava Beds | Exact 90% | Exact 100% | This type is considered adequate as mapped. |
| 3 | Rock Outcrop and Scree Shrubland | Acceptable 100% | Understandable 38% | Omission accuracy remained below the standard even with the least restrictive criteria, indicating that incidences of this type were often omitted from the map. This map class is often less than the minimum map unit in size (84% of all polygons were <.5 ha. in size) so omissions might be expected. Merging this map class into adjacent polygons would increase the accuracy of the overall map, however there is value in having known occurrences mapped. |
| 4 | Wild Buckwheat-Sand Bluestem Sparse Vegetation | Understandable 62% | Understandable 76% | 36% of this map class occurs below the MMU. When misclassified it was shown on the map as Cinder Sparse Mosaic or Apache Plume / Cinder Sparse Vegetation. Sparse shrub and tall grassland communities (Map classes 4 & 5) may need to be considered as a single map class due to the constraints in photointerpreting them. |
| 5 | Apache Plume/Cinder Sparse Vegetation | Acceptable 83% | Understandable 70% | This map class was sometimes misclassified as Wild Buckwheat – Sand Bluestem Sparse Vegetation (omission error), which typically occurs in cinders and has a similar formation type. |
| 6 | Lava Bed Sparse Vegetation | Acceptable 83% | Exact 91% | This type is considered adequate as mapped. |
| 7 | Sand Bluestem Herbaceous Vegetation | Understandable 83% | Understandable 100% | This type is considered adequate as mapped. |
| 8-10 | Montane Grassland | Understandable 71% | Understandable 80% | On the map this class was misclassified as Ponderosa Pine Invasive Vegetation, Ponderosa Pine Montane Grass Mosaic, and Ponderosa Pine Cinder Woodland (omission error). Many polygons of this class interfinger between ponderosa pine dominated canopies. This class was mapped as Rock Outcrop and Scree Shrubland and Wild Buckwheat-Sand Bluestem Sparse Vegetation (omission error) and misclassified as Ponderosa Pine Invasive Vegetation and Montane Grassland (commission error). Small patches of Montane Grassland adjacent to ponderosa pine dominated canopies could be combined into the large-scale ponderosa pine herbaceous understory map classes to increase accuracy. |

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| | | | | |
|-------|--|------------------------|------------------------|--|
| 11-12 | Pinyon Pine-Utah Juniper/Blue Grama Woodland | Exact 83% | Acceptable 83% | This type is considered adequate as mapped. |
| 13 | Limber Pine Woodland | Exact 83% | Understandable 86% | On the map this class was misclassified as Ponderosa Pine or Douglas-fir dominated class (omission error). |
| 14 | Ponderosa Pine/Cinder Woodland | Understandable 86% | Understandable 100% | The most common errors confused this type with Montane Grassland, Lava Bed Sparse Vegetation, or ponderosa pine dominated classes with Apache Plume or montane grassland understory. |
| 15 | Ponderosa Pine/Montane Grass Mosaic | Understandable 100% | Acceptable 89% | In the field areas where this class was found, it was mapped as Ponderosa Pine/Apache Plume Woodland (commission error). |
| 16 | Ponderosa Pine Invasive Herbaceous Vegetation | Understandable 82% | Understandable 82% | This class is most often confused with Montane Grassland. |
| 17-19 | Ponderosa Pine/Apache Plume Woodland | Understandable 74% | Understandable 96% | This class is often confused with Pinyon Pine-Utah Juniper/Blue Grama Woodland and Apache Plume / Cinder Sparse Vegetation (omission error) and as Ponderosa Pine / Montane Grass Mosaic (commission error). |
| 20 | Ponderosa Pine/Sand Bluestem Woodland | Understandable 80% | Understandable 96% | This class is often confused with Ponderosa Pine Cinder Woodland or Apache Plume/Cinder Sparse Vegetation. |
| 21 | Douglas-fir Forest | Acceptable 83% | Understandable 100% | This type is considered adequate as mapped. |
| 22 | Transportation, Communications, and Utilities | Acceptable 100% | Acceptable 100% | This type is considered adequate as mapped. |
| 23 | Facilities | Acceptable 100% | Acceptable 100% | This type is considered adequate as mapped. |
| 24 | Residential Land | N/A | N/A | This class was not accuracy assessed because private lands were not accessible. |
| 25 | Reservoirs and Trick Tanks | Acceptable 100% | Acceptable 100% | This type is considered adequate as mapped. |
| 26 | Strip Mines, Quarries, and Gravel Pits | Understandable 100% | Exact 100% | This class is sometimes misclassified as Cinder Sparse Vegetation. |
| 27 | Croplands and Pastures | Acceptable 100% | Acceptable 100% | This type is considered adequate as mapped. |

Table 7. Accuracy assessment contingency table (criteria 5, exact match) and statistical analysis of reference data with map class data.

| Map Class Data | | Reference Data (Field Data for Accuracy Assessment Classes) | | | | | | | | | | | | | | | | | | | | | | | | | | Total | Commission Accuracy | 90% Confidence Intervals | |
|----------------|--------------------------|---|-------|-------|------|------|------|-------|------|-------|------|------|------|------|-------|------|------|------|-------|------|----|------|------|----|---|------|-------|-------|---------------------|--------------------------|--|
| | Map Code | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8-10 | 11-12 | 13 | 14 | 15 | 16 | 17-19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | N | (% Correct) | - | + | | | | |
| | 1 | 20 | | 1 | 1 | 2 | 1 | | | | | 1 | | | 3 | | | | 1 | | | | | 30 | 66.7 | 55.1 | 81.6 | | | | |
| | 2 | 1 | 9 | | | | | | | | | | | | | | | | | | | | | 10 | 90.0 | 65.3 | 97.7 | | | | |
| | 3 | 1 | | 3 | | | | | 1 | | | | | | | | | | | | | | | 5 | 60.0 | 27.3 | 85.7 | | | | |
| | 4 | 5 | | | 7 | 8 | | | | | | | | 1 | | | | | | | | | | 21 | 33.3 | 20.0 | 53.4 | | | | |
| | 5 | 4 | | 2 | 2 | 19 | | | | 1 | | | | 1 | | | | | | | | | | 29 | 65.5 | 48.3 | 76.1 | | | | |
| | 6 | | | | | 6 | 19 | | | | | 4 | | | 1 | | | | | | | | | 30 | 63.3 | 48.3 | 76.1 | | | | |
| | 7 | | | | 1 | 3 | | 1 | | | | | | | 1 | | | | | | | | | 6 | NA | NA | NA | | | | |
| | 8-10 | | | 4 | 2 | | | | | 16 | | | 1 | 4 | | | | | 1 | | | | | 28 | 57.1 | 6.4 | 27.4 | | | | |
| | 11-12 | | | 1 | | 2 | | | | 1 | 25 | | | 1 | | | | | | | | | | 30 | 83.3 | 69.5 | 91.6 | | | | |
| | 13 | | | | | | | | | 1 | 5 | | | | | | | | | | | | | 6 | 83.3 | 43.5 | 95.4 | | | | |
| | 14 | 2 | | 1 | | | | | | 3 | | 1 | 13 | 2 | | 5 | 1 | 1 | | | | | | 29 | 44.8 | 32.6 | 61.3 | | | | |
| | 15 | | | | | | | | | 7 | | 1 | 2 | 14 | 2 | 3 | | 1 | | | | | | 30 | 46.7 | 32.6 | 61.3 | | | | |
| | 16 | | | | 3 | 1 | | | | 9 | 1 | | 1 | 1 | 5 | | | | | | | 1 | | 22 | 22.7 | 14.2 | 47.1 | | | | |
| | 17-19 | 2 | | 2 | | 5 | 1 | 1 | | 4 | | 3 | 2 | 1 | 9 | | 1 | | | | | | | 31 | 29.0 | 15.6 | 39.3 | | | | |
| | 20 | | | | | 2 | | | | | | 1 | | | | | 2 | | | | | | | 5 | 40.0 | 14.3 | 72.8 | | | | |
| | 21 | | | | | | | | | | | 2 | 1 | 1 | | | | 2 | | | | | | 6 | 33.3 | 11.7 | 65.3 | | | | |
| | 22 | | | | | | | | | | 1 | | | | | | | | | 1 | | | | 2 | 50.0 | 12.1 | 87.9 | | | | |
| | 23 | | | | | | | | | | | 1 | | | | | | | | 3 | | | | 4 | 75.0 | 35.6 | 94.2 | | | | |
| | 24 | | | | | | | | | | | | | | | | | | | | 0 | | | 0 | NA | NA | NA | | | | |
| | 25 | 2 | | | | | | | | | | | | | | | | | | | | 0 | | 2 | 0.0 | 27.0 | 100.0 | | | | |
| | 26 | | | | | | | | | | | | | | | | | | | | | | 6 | 6 | 100.0 | 46.0 | 91.4 | | | | |
| | 27 | | | | | | | | | | | | | | | | | | | | 1 | | 0 | 1 | NA | 27.0 | 100.0 | | | | |
| | Total | N | 37 | 9 | 14 | 16 | 48 | 21 | 2 | 37 | 32 | 10 | 27 | 21 | 15 | 22 | 3 | 5 | 2 | 4 | 1 | 0 | 7 | 0 | Total Sampling Points: 334 Total Correct: 179 Overall Accuracy: 53.92% Kappa Index: 50.09% 90% Confidence Intervals: 43.72%, 64.06% | | | | | | |
| | Omission Accuracy | (% Correct) | 54.1 | 100.0 | 21.4 | 43.8 | 39.6 | 90.5 | 50.0 | 43.2 | 78.1 | 50.0 | 48.1 | 66.7 | 33.3 | 40.9 | 66.7 | 40.0 | 50.0 | 75.0 | NA | NA | 85.7 | NA | | | | | | | |
| | 90% Confidence Intervals | - | 42.1 | 76.9 | 8.9 | 32.5 | 27.0 | 74.9 | 27.0 | 31.4 | 64.2 | 21.8 | 35.2 | 48.7 | 18.6 | 24.4 | 25.4 | 14.3 | 12.1 | 52.6 | NA | NA | 54.8 | NA | | | | | | | |
| | + | 67.7 | 100.0 | 43.2 | 73.9 | 48.8 | 96.8 | 100.0 | 56.6 | 87.7 | 69.7 | 64.8 | 80.1 | 57.5 | 56.2 | 92.2 | 72.8 | 87.9 | 100.0 | NA | NA | 96.8 | NA | | | | | | | | |

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Table 8. Accuracy assessment contingency table (criteria 4, acceptable accuracy) and statistical analysis of reference data with map class data.

| Map Class Data | | Reference Data (Field Data for Accuracy Assessment Class) | | | | | | | | | | | | | | | | | | | | Total | Commission Accuracy | 90% Confidence Intervals | | | |
|--------------------------|-------------|---|-------|-------|------|------|------|------|------|-------|-------|------|------|------|-------|------|------|-------|-------|-------|------|-------|---------------------|--|-------|-------|-------|
| | Map Code | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8-10 | 11-12 | 13 | 14 | 15 | 16 | 17-19 | 20 | 21 | 22 | 23 | 25 | 26 | 27 | N | (% Correct) | - | + | |
| | 1 | 24 | | 1 | 1 | 2 | 1 | | | | | | | | 1 | | | | | | | | 30 | 80.0 | 65.7 | 89.3 | |
| | 2 | | 10 | | | | | | | | | | | | | | | | | | | | 10 | 100.0 | 78.7 | 100.0 | |
| | 3 | | | 5 | | | | | | | | | | | | | | | | | | | 5 | 100.0 | 64.9 | 100.0 | |
| | 4 | 1 | | | 12 | 8 | | | | | | | | | | | | | | | | | 21 | 57.1 | 39.6 | 73.1 | |
| | 5 | 1 | | 1 | 2 | 24 | | | | | | | | 1 | | | | | | | | | 29 | 82.8 | 68.6 | 91.3 | |
| | 6 | | | | | 2 | 25 | | | | | 3 | | | | | | | | | | | 30 | 83.3 | 69.5 | 91.6 | |
| | 7 | | | | 1 | 3 | | 2 | | | | | | | | | | | | | | | 6 | 33.3 | 11.7 | 65.3 | |
| | 8-10 | | | 3 | 2 | | | | 19 | | | | | 4 | | | | | | | | | 28 | 67.9 | 52.3 | 80.2 | |
| | 11-12 | | | 1 | | 2 | | | 1 | 25 | | | | 1 | | | | | | | | | 30 | 83.3 | 69.5 | 91.6 | |
| | 13 | | | | | | | | | | 6 | | | | | | | | | | | | 6 | 100.0 | 68.9 | 100.0 | |
| | 14 | 2 | | 1 | | | | | 3 | | 1 | 17 | 2 | | 1 | 1 | 1 | | | | | | 29 | 58.6 | 43.5 | 72.3 | |
| | 15 | | | | | | | | 1 | | 1 | | 23 | 1 | 3 | | 1 | | | | | | 30 | 76.7 | 62.1 | 86.8 | |
| | 16 | | | | 3 | 1 | | | 9 | 1 | | 1 | 1 | 5 | | | | | | | 1 | | 22 | 22.7 | 11.5 | 39.9 | |
| | 17-19 | 2 | | 2 | | 5 | | 1 | | 4 | | 1 | | | 16 | | | | | | | | 31 | 51.6 | 37.3 | 65.6 | |
| | 20 | | | | | 1 | | | | | | 1 | | | | 3 | | | | | | | 5 | 60.0 | 27.2 | 85.7 | |
| | 21 | | | | | | | | | | | 1 | | | | | 5 | | | | | | 6 | 83.3 | 49.8 | 96.2 | |
| | 22 | | | | | | | | | | | | | | | | | 2 | | | | | 2 | 100.0 | 42.5 | 100.0 | |
| | 23 | | | | | | | | | | | | | | | | | | 4 | | | | 4 | 100.0 | 59.7 | 100.0 | |
| | 25 | | | | | | | | | | | | | | | | | | | 1 | | | 1 | 100.0 | 27.0 | 100.0 | |
| | 26 | 2 | | | | | | | | | | | | | | | | | | | | 6 | 8 | 75.0 | 46.0 | 91.3 | |
| | 27 | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 100.0 | 27.0 | 100.0 |
| | Total | N | 32 | 10 | 14 | 21 | 48 | 26 | 3 | 33 | 30 | 8 | 24 | 26 | 12 | 21 | 4 | 7 | 2 | 4 | 1 | 7 | 1 | Total Sampling Points: 334 Total Correct: 235 Overall Accuracy: 70.3% Kappa Index: 68.02% 90% Confidence Intervals: 69.0%, 84.0% | | | |
| Omission Accuracy | (% Correct) | 75.0 | 100.0 | 35.7 | 57.1 | 50.0 | 96.2 | 66.7 | 57.6 | 83.3 | 75.0 | 70.8 | 88.5 | 41.7 | 76.2 | 75.0 | 71.4 | 100.0 | 100.0 | 100.0 | 85.7 | 100.0 | | | | | |
| 90% Confidence Intervals | - | 65.7 | 78.7 | 64.9 | 39.6 | 68.6 | 69.5 | 11.7 | 52.3 | 69.5 | 68.9 | 43.5 | 62.1 | 11.5 | 37.3 | 27.2 | 49.8 | 42.5 | 59.6 | 27.0 | 46.0 | 27.0 | | | | | |
| | + | 89.2 | 100.0 | 100.0 | 73.1 | 91.3 | 91.6 | 65.3 | 80.2 | 91.6 | 100.0 | 72.3 | 86.8 | 39.9 | 65.6 | 85.7 | 96.2 | 100.0 | 100.0 | 100.0 | 91.3 | 100.0 | | | | | |

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Table 9. Accuracy assessment contingency table (criteria 3, understandable accuracy) and statistical analysis of reference data with map class data.

| Map Class Data | | Reference Data (Field Data for Accuracy Assessment Class) | | | | | | | | | | | | | | | | | | | | Total | Commission Accuracy | 90% Confidence Intervals | | | |
|----------------|--------------------------|---|------|-------|------|------|------|------|-------|-------|------|------|-------|-------|-------|------|-------|-------|-------|-------|-------|-------|---------------------|--|-------|-------|-------|
| | Map Code | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8-10 | 11-12 | 13 | 14 | 15 | 16 | 17-19 | 20 | 21 | 22 | 23 | 25 | 26 | 27 | N | (% Correct) | - | + | |
| | 1 | 27 | | 1 | | | 1 | | | | | | | | 1 | | | | | | | | 30 | 90.0 | 77.4 | 95.9 | |
| | 2 | | 10 | | | | | | | | | | | | | | | | | | | | 10 | 100.0 | 78.7 | 100.0 | |
| | 3 | | | 5 | | | | | | | | | | | | | | | | | | | 5 | 100.0 | 64.9 | 100.0 | |
| | 4 | | | | 13 | 8 | | | | | | | | | | | | | | | | | 21 | 61.9 | 44.1 | 77.0 | |
| | 5 | | | | 2 | 26 | | | | | | | | 1 | | | | | | | | | 29 | 89.7 | 76.8 | 95.8 | |
| | 6 | | | | | | 30 | | | | | | | | | | | | | | | | 30 | 100.0 | 91.7 | 100.0 | |
| | 7 | | | | | 1 | | 5 | | | | | | | | | | | | | | | 6 | 83.3 | 49.8 | 96.2 | |
| | 8-10 | | | 3 | 2 | | | | 20 | | | | | 3 | | | | | | | | | 28 | 71.4 | 56.0 | 83.1 | |
| | 11-12 | | | 1 | | | | | 1 | 28 | | | | | | | | | | | | | 30 | 93.3 | 81.7 | 97.8 | |
| | 13 | | | | | | | | | | 6 | | | | | | | | | | | | 6 | 100.0 | 68.9 | 100.0 | |
| | 14 | | | 1 | | | | | 2 | | 1 | 25 | | | | | | | | | | | 29 | 86.2 | 72.6 | 93.7 | |
| | 15 | | | | | | | | | | | | 30 | | | | | | | | | | 30 | 100.0 | 91.7 | 100.0 | |
| | 16 | | | | | 1 | | | 2 | | | | | 18 | | | | | | | 1 | | 22 | 81.8 | 65.1 | 91.6 | |
| | 17-19 | 2 | | 2 | | | | | | 4 | | | | | 23 | | | | | | | | 31 | 74.2 | 59.7 | 84.8 | |
| | 20 | | | | | 1 | | | | | | | | | | 4 | | | | | | | 5 | 80.0 | 43.5 | 95.4 | |
| | 21 | | | | | | | | | | | | | | | | 6 | | | | | | 6 | 100.0 | 68.9 | 100.0 | |
| | 22 | | | | | | | | | | | | | | | | | 2 | | | | | 2 | 100.0 | 42.5 | 100.0 | |
| | 23 | | | | | | | | | | | | | | | | | | 4 | | | | 4 | 100.0 | 59.7 | 100.0 | |
| | 25 | | | | | | | | | | | | | | | | | | | 1 | | | 1 | 100.0 | 27.0 | 100.0 | |
| | 26 | 2 | | | | | | | | | | | | | | | | | | | | 6 | 8 | 75.0 | 46.0 | 91.3 | |
| | 27 | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 100.0 | 27.0 | 100.0 |
| | Total | N | 31 | 10 | 13 | 17 | 37 | 31 | 5 | 25 | 32 | 7 | 25 | 30 | 22 | 24 | 4 | 6 | 2 | 4 | 1 | 7 | 1 | Total Sampling Points: 334 Total Correct: 290 Overall Accuracy: 86.8% Kappa Index: 85.8% 90% Confidence Interval: 84.1%, 95.4% | | | |
| | Omission Accuracy | (% Correct) | 87.1 | 100.0 | 38.5 | 76.5 | 70.3 | 96.8 | 100.0 | 80.0 | 87.5 | 85.7 | 100.0 | 100.0 | 81.8 | 95.8 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 85.7 | 100.0 | | | | |
| | 90% Confidence Intervals | - | 74.2 | 78.7 | 20.2 | 56.7 | 56.9 | 86.8 | 64.9 | 64.2 | 74.9 | 54.8 | 90.2 | 91.7 | 65.1 | 83.3 | 60.0 | 68.9 | 42.5 | 59.6 | 27.0 | 54.8 | 27.0 | | | | |
| | | + | 84.1 | 100.0 | 60.7 | 90.0 | 80.9 | 99.3 | 100.0 | 89.9 | 57.4 | 96.7 | 100.0 | 100.0 | 91.6 | 99.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 96.7 | 100.0 | | | | |

5. DISCUSSION

The vegetation at SUCR represents the results of primary succession 800 years after the volcanic reshaping of the landscape. This unique environment provided several challenges to vegetation mapping and can be summarized below:

- 1) Sparse vegetation is difficult to photointerpret and classify, especially if the substrate has a strong spectral signal, such as in cinder and lava. A strong spectral signature appears to have reduced the accuracy of mapped ponderosa pine classes with sparse understory communities (i.e. Ponderosa Pine / Apache Plume Woodland was often misclassified as Ponderosa Pine / Cinder Woodland and Ponderosa Pine / Montane Grass Mosaic).
- 2) Many new associations were described in the course of this project. NatureServe usually considered field relevés with less than five occurrences as local assemblages or provisional associations due to no previous data collection. With more extensive vegetation sampling and classification in northern Arizona, some of the types currently described as local assemblages or provisional associations may be assigned association status. Associations were not always the best mapping classes and some associations were aggregated into mosaics (i.e. Ponderosa Pine / Montane Grass Mosaic contains both the *Pinus ponderosa* / *Muhlenbergia montana* Woodland and *Pinus ponderosa* / *Bouteloua gracilis* Woodland association).
- 3) Scale changes between the preliminary map in 2001 and the final map in 2002 influenced the accuracy assessment results. Polygons that were assessed in 2001 when overlaid with the 2002 final vegetation map were found to be significantly different in size and shape. There were more preliminary polygons drawn at less than the MMU on the 2001 map. Project resources did not allow re-sampling of all 2001 data points in order to eliminate all these errors; although we did review each point and eliminated those that were suspected of representing that type of error. These changes resulted in differences in scale assessments of the polygons and probably reduced our overall map accuracy. Two-thirds of the accuracy assessment reference data were obtained in 2001 and showed a total accuracy of 48% using only these points. In 2002 the overall accuracy was 63% (exact criteria) using just 2002 collected reference data. For instance, Apache Plume Cinder Sparse Shrubland often occurred in small openings in ponderosa pine woodlands and was often interpreted as Ponderosa Pine / Apache Plume Woodland depending on the scale of the assessment.
- 4) The field key used for the accuracy assessment was not reviewed by the photointerpreters before accuracy assessment in 2001. It is recommended that all field keys be reviewed by the photointerpreters prior to accuracy assessment.
- 5) The field data collection, 1999, and accuracy assessment, 2001 and 2002, may be measuring land cover characteristics that are different from those shown on the 1996 photography used for map creation. Land surface changes since the 1996 aerial photography may be significant from the 1999 field sampling and the 2001/2002 accuracy assessment. Changes include land use, which caused alteration and development, recreational activities, fire and non-native

plant invasion composition. Seasonal vegetation changes from the time the aerial photographs were acquired (October 1996) to the time classification relevés and accuracy assessment observation points were sampled (summer 1999, 2000, 2001, and 2002) complicated the interpretation, since the dormant vegetation that was evident in the fall presents a different ecological aspect than summer vegetation. The difficulty of this task was increased because of the long shadows in October when both sets of photos were flown. New aerial photography flown near the summer solstice (June 21) would have minimized the shadow problem. Other problems with interpretation and digital transfer arose because the aerial photos and the DOQQs were flown in different years and exhibit different ground conditions. If new photography were used at the start of this project, at the time of this report the database's ground condition would only be three years old, not six years old. During the course of the SUCR vegetation mapping project, the Arizona Department of Transportation began widening U.S. Highway 89, which runs north and south along the western edge of the mapping area. The resulting changes in vegetation were not documented in the October 1996 photography. The highway was being expanded from a narrow two-lane highway to a four-lane highway with turning lanes and acceleration and deceleration lanes (Figure 14). In addition, the highway was widened so that "islands" of native vegetation, typically stands of ponderosa pine with a graminoid understory, remained in the median strip between the northbound and southbound travel lanes.



Figure 14. Photos illustrating reconstruction of portions of U.S. Highway 89.

At the southern end of this highway reconstruction project, the affected plant association is mapped as predominantly ponderosa pine woodlands with a mix of grasses and cinder in the understory. At the northernmost end of the highway reconstruction project the vegetation is montane grasslands and pinyon-juniper woodlands. Given the width of the reconstruction project, it is possible that nearly the entire stand of ponderosa pine was removed, or only a small portion may remain isolated in the median strip. Digital data showing the extent and location of the highway reconstruction was not available at the time we mapped SUCR. Once the highway data become available, the vegetation database should be revised to account for the new road cut and to re-calculate vegetation acreages. These map class changes may occur frequently enough to have caused misclassified polygons and therefore decrease the measured total accuracy assessment.

- 6) Twenty-eight percent of the total number of polygons were mapped at below the MMU. Accuracy assessment of these polygons is problematic due to the high amount of resources needed to correctly locate and assess these polygons. This not only increased the number of required polygons for accuracy assessment but also caused problems in interpretation of some classes. For example, Montane Grassland routinely occurs in small patches

interspersed among ponderosa pine and depending upon the scale of photointerpretation and field evaluation could often be confused with Ponderosa Pine / Montane Grass Mosaic. In addition, under a tree canopy GPS accuracy was often insufficient to conclusively place the field technician within polygons less than 0.5 hectares, particularly when the polygon may have had convoluted shapes.

- 7) The number and variability of vegetation signatures sometimes made them difficult to distinguish and interpret consistently. Environmental factors such as moisture gradients, slope exposure, presence and density of exotic grasses and forbs, and soil diversity result in several photographic signatures for each grassland and some shrub and woodland classes. Aerial photograph signatures in the ponderosa pine types were challenging to interpret because of dense mats of ponderosa pine litter and heavy layers of dust generated from pumice mining operations and recreation vehicle trails. Both conditions created a photosignature similar to that of dormant blue grama grass. Photography flown when the grass was green would have aided in distinguishing litter and dust from grass. Extensive ground reconnaissance and a number of accuracy assessment observation points were used to determine where the understory consisted of grasses or other herbaceous species versus mats of pine litter (Figures 15).



Figure 15. Typical ponderosa pine stands with pine litter and graminoid understories.

- 8) Color photography flown with more appropriate timing for this mapping project would have eliminated many of the problems and delays this project experienced. For example, RSGIG technicians spent a great deal of time trying to locate registration points on the aerial photos and the DOQQs.

Vegetation classification and map classes

Over 25% of the alliances and 35% of the associations were newly defined during the course of this project; the remainder was described as local assemblages described during the course of this project or incorporated into existing community classification. Most of the diversity of associations occurred within the woodland formation class. Ten of the 17 associations were directly translatable into map classes; the remaining associations were combined to form mosaics of vegetation as a map class. Additional detail in land use, canopy cover and associated species was photo-delineated for three of the associations and this additional detail was represented as map class modifiers. While the modifiers provided additional important information to the map, for accuracy assessment only map classes and not modifiers were analyzed.

Forests in the SUCR project area are not common. Although the term “ponderosa pine forest” is commonly used to describe the vegetation communities in the park, most of the ponderosa pine dominated areas have less than 75% canopy cover and contain a more open park-like canopy structure. Only in small patches at higher elevations on Darton Dome and O’Leary Peak does Douglas-fir and pinyon-pine forest canopy ever reach these cover values. Downslope these community types gradate quickly into a more open woodland-like formation. Therefore, most of our tree dominated vegetation communities fall within the sparser woodland communities.

Woodlands are represented mainly by ponderosa pine associations. The average tree cover for these associations is often a sparse 15% canopy cover. Although ponderosa pine associations throughout their range typically contain higher cover, at SUCR the primary successional environment limits tree establishment and growth rates. In fact, most of the ponderosa pine trees at SUCR have bent, distorted and exposed roots suggesting high environmental stress with deep cinder limiting seedling development. The ponderosa pine communities tend to have a few large trees and a sparse understory. These sparse understory species were difficult to distinguish on the aerial photography.

Only one NVCS shrubland alliances was defined in this project; the remaining shrublands were described in the sparse lifeform or as local shrubland stands. Due to the sparse patchiness of the landscape, and the large scale 1,000m² relevés, true shrublands were a minor type sampled. A mosaic, Rock Outcrop and Scree Shrubland, map class was developed to describe many of the small sparse stands of shrubs. As well, a sparse Apache Plume community often occurred in small patches in cinder barrens and in gaps of the ponderosa pine woodlands.

Five herbaceous associations were described and aggregated into three mappable classes. These were combined due to difficulty separating them in the photointerpretation. Most of the herbaceous associations were sampled using a small scale relevé (400m²), due to the density of the vegetation in these communities. Even after combining the communities, they were often misidentified on the map. Montane grasslands were often misclassified as invasive herbaceous types and vice versa. This problem not only stems from misinterpretation in the photo-delineation process, but from seasonal changes in herbaceous plant communities. It is likely that an area that had an invasive photosignature in 1996 no longer maintained the same species composition during the 2001 and 2002 field season. These errors represent a lapse of time between the photo acquisition and the project completion.

Although only two associations and one local assemblage were defined as sparse vegetation associations, many of the relevés placed in the woodland and herbaceous lifeforms contain less than 25% total vegetation cover. In order to not artificially proliferate associations based solely on their cover values they were combined based on similarities of their species composition and the cover ranges described for each association. The distinction between sparse communities and alternate placement in a woodland, shrub or herbaceous class is still under general review in the NVCS. At the time of classification only seven sparse alliances were represented in the NVCS classification. Further park classification work may have different standards and recommendations and may result in an altered placement of relevés than was determined in the course of this study.

The USGS-NPS vegetation mapping projects are designed to produce both a vegetation classification and a set of map classes. Typically the systems are very similar, but sometimes there is not a strict one-to-one correspondence between the two. Photographic interpretation is based on the ability to accurately and consistently delineate map classes based on complex signatures. Vegetation characteristics that can be seen on aerial photography are not necessarily the same as those apparent on the ground and vice versa. Field reconnaissance and map verification work by the photointerpreters aided enormously in developing the map classes and discerning the inherent variability of each photographic signature. Close collaboration between the mappers and the ecologists doing the classification was critical to each understanding the concepts behind the plant associations and map classes.

Accuracy assessment

The USGS-NPS park mapping program has the standard of 80% overall map accuracy and for each class. The map did not meet this accuracy using the exact (53.9%) or acceptable (70.3%) accuracy criteria, but it did using the understandable criteria (86.8%). The acceptable accuracy best describe the functional map accuracy and while it is lower than the standard, we believe the map is usable as long as the assessments for each individual map class are reviewed and are kept in mind when the map is being used for management purposes. Most of the error in the map can be directly attributed to known sources and not to gross error in photointerpretation.

Applications

The vegetation map is ready for use with the knowledge that some of the map classes are below the desired 80% accuracy. These map classes may need to be aggregated depending on the desired accuracy needed for a particular project. Map classes can be aggregated to the NVCS alliance level or to the lifeform.

This map will provide the baseline vegetation data that will allow for better resource management of the park. As with other USGS-NPS park management programs, it is possible that this map will assist with many different aspects of planning activities, including fire management planning, habitat modeling, field sampling for threatened and endangered species, research of particular species and their habitats, education and interpretation, and trail maintenance. This study will also help to compare habitats across management boundaries and hopefully to assist in the joint-agency management of the lands studied in the project environs. Ultimately, the vegetation map will help to monitor impacts on vegetation health as well as the overall ecosystem health of the area.

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7. GLOSSARY

The following people contributed to this glossary: Alan Bell, Jack Butler, Daniel Cogan, Janet Coles, Doug Crawford, Dave Eckhardt, Monica Hansen, and Tom Owens.

This glossary refers to terms as they are used in USGS-NPS vegetation mapping projects. Some terms may not appear in this report.

7.5-Minute Quadrangle. Informally known as a 'quad' map. A USGS paper map product at 1:24,000 scale covering 7.5 minutes of latitude and 7.5 minutes of longitude. Features shown include elevation contours, roads, railroads, water bodies, buildings, urban developments, wooded cover, permanent ice fields, and wetlands. This is a basic layer of information for many ecological and natural resource applications. A digital version of a 7.5-minute quad is called a Digital Raster Graphic (DRG).

Accuracy. The closeness of results of observations, computations, or estimates to the true values or to values that are accepted as being true (ASP 1984). See also Error.

Accuracy Assessment (AA). The process of determining the thematic accuracy of the vegetation map. An unaffiliated ecologist tests map accuracy after the vegetation mapping and classification are complete. (Stadelmann et al. 1994).

Accuracy Assessment Point. A location where accuracy assessment data are collected. See "Producing rigorous and consistent accuracy assessment procedures" at <http://biology.usgs.gov/npsveg/aa/aa.html> for more information.

Aerial Photography. Photography taken from an airplane (not satellite) mounted with

specially designed photographic equipment. Ideally, the lens and the film are parallel to the surface being photographed. A sequence of aerial photographs along a flight line will have a certain amount of overlap so that the photos can be viewed with a stereoscope. "Sidelap" refers to overlap between flight lines (ASP 1984). Print size is usually 9"x9" and are photos that may use true color or color infrared film.

Alliance. A physiognomically uniform group of associations sharing one or more diagnostic (dominant or indicator) species that usually occur in the uppermost stratum of the vegetation (FGDC 1997). This is the second finest level in the NVCS hierarchy.

Anderson Classification System.

A classification system developed for use with remote sensing systems in the 1970s adopted for the National Vegetation Classification Standard to map cultural and water features (Anderson et al. 1976).

| Level I | Level II |
|-------------------------------|---|
| Urban or Built-up Land | Residential |
| | Commercial and Services |
| | Industrial |
| | Transportation, Communications, and Utilities |
| | Industrial and Commercial Complexes |
| | Mixed Urban or Built-up Land |
| | Other Urban or Built-up Land |
| Agricultural Land | Cropland and Pasture |
| | Orchards, Vineyards, and Ornamental Horticultural Areas |
| | Confined Feeding Operations |
| | Other Agricultural Lands |
| | |
| Water (non-vegetated portion) | |
| | Streams and Canals |
| | Lakes |

| | |
|-------------|--|
| | Reservoirs |
| | Bays and Estuaries |
| Barren Land | |
| | Dry Salt Flats |
| | Beaches |
| | Sandy Areas other than Beaches |
| | Strip Mines, Quarries, and Gravel Pits |
| | Transitional Areas |
| | Mixed Barren Lands |

ArcInfo. A geographic information software used to view and analyze data.

Association. The finest level of the NVCS classification hierarchies. A physiognomically uniform group of stands of vegetation that share one or more diagnostic overstory and understory species. These elements occur as repeated patterns of assemblages across the landscape, and are generally found under similar habitat conditions (FGDC 1997).

Attribute (digital data). A numeric, text, or image data field in a relational database table (such as a GIS) that describes a spatial feature such as a point, line, polygon, or cell (ESRI 1994).

Automation. The process of entering data into a computer (see also Digitize).

Base map. The control to which all spatial data is georeferenced. Interpreted photo data are transferred to a base map to rectify and register the data. In this project the base maps are USGS DOQQs.

Bureau of Reclamation (USBR, BOR).

A U.S. Department of Interior agency created in 1902 and charged with developing environmentally and economically sound irrigation and hydropower projects in 17 Western States. The Remote Sensing and

GIS Group of the BOR manages a number of park projects for the USGS-NPS Vegetation Mapping Program.

Biological Resources Discipline (BRD). A USGS discipline housing the Center for Biological Informatics. The BRD's mission is to work with others to provide the scientific understanding and technologies needed to support the sound management and conservation of our Nation's biological resources. Formerly, the National Biological Service (NBS).

Center for Biological Informatics (CBI). A USGS Science Center. CBI serves as the operating agent for the National Biological Information Infrastructure. In addition, CBI manages the USGS-NPS Vegetation Mapping Program along with other national data collection programs that complement and strengthen its role within the NBII.

Class. The level in the NVCS hierarchies based on the structure of the vegetation. Class is determined by the relative percentage of cover and the height of the dominant, uppermost life forms (Grossman et al. 1998).

Classification Accuracy. How closely the map classes match the vegetation found on the landscape. This is determined by accuracy assessment protocols. See "Producing rigorous and consistent accuracy assessment procedures" at <http://biology.usgs.gov/npsveg/aa/aa.html> for more information.

Color Infrared (CIR) Film. A three-layer color film sensitized to green, red, and near-infrared portions of the spectrum. CIR films emphasize differences in infrared reflectance from surfaces and are some of the most useful aerial films currently available for use in agricultural and vegetation surveys. The images are sharper and have better contrast

than conventional color photos because they are less susceptible to atmospheric light scattering. Furthermore, CIR has a high transmission component through green leaves, meaning that it can detect layers of leaves lower in the canopy. In true-color photography, the photosynthetic pigments within leaves quickly absorb visible light, and the film records information about nothing below the uppermost leaf layer. Color differences recorded on CIR film are used to differentiate among vegetation types. Generally, in spring and summer, healthy deciduous trees and other vegetation photographs as magenta or red, while healthy evergreens photograph more as a brownish red. CIR film can only be used in daylight.

Commission Accuracy. See Producer's Accuracy.

Community. An assemblage of species that co-occur in defined areas at certain times and have the potential to interact with one another (Grossman et al. 1998). In the NVCS, Association and Community are synonyms.

Community Element Global (CEGL). NatureServe's unique plant association coding system in their central biodiversity database; also known as Elcode.

Community Type. See Association or Type.

Complex. A group of associations that are not distinguishable from one another on aerial photography and so are grouped into a map class. Compare with Mosaic.

Confusion Matrix. See Contingency Table.

Contingency Table. A table that is used in accuracy assessment to determine the degree of misclassification that has occurred. The

table compares the classes derived from accuracy assessment relevés to the classes derived from photointerpretation. Also referred to as Error Matrix, Confusion Matrix, or Misclassification Matrix.

Coordinate System. A reference system that represents horizontal and/or vertical locations and distances on a map. A geographic coordinate system is the latitude and longitude with respect to a reference spheroid. A local coordinate system is one that is not aligned with the Earth's surface. Most coordinate systems are based on projections of the earth's surface onto a plane. All spatial data in this project uses the Universal Transverse Mercator (UTM) coordinate system.

Cover. The area of ground covered by the vertical projection of the aerial parts of vegetation (FGDC 1997).

Cover Type. A designation based upon the plant species forming a plurality of composition within a given area (e.g., Oak-Hickory) (FGDC 1997). It is roughly equivalent to an Alliance in the NVCS classification hierarchy.

Coverage. A data theme in a geographic information system with vector and polygon topology and attribute data related to that topic. Also, the file format used by Arc/Info software for vector spatial data.

Cowardin Classification. A wetland classification system used as the FGDC standard for wetland classification (Cowardin et al. 1979).

Crosswalk. The relationship between the elements of two classification systems. For example, this project includes a crosswalk between Map Classes and units of the

NVCS. In a database, the crosswalk is in a Lookup Table (LUT).

Cultural Vegetation. Vegetation planted or actively maintained by humans such as annual croplands, orchards, and vineyards. Contrast with Natural Vegetation.

Datum. A mathematical model that describes the shape of the earth. The earth is not a sphere but is rather an ellipsoid distorted by rotation about its axis, bulging at the equator and flattened at the poles. Because of the distribution of continents and seas, the distortion is not uniform around the globe and there are datums for different parts of the earth based on different measurements (Snyder 1982). The datum used by this project is NAD83.

Datum (horizontal-control). The position on the spheroid of reference assigned to the horizontal control of an area. A datum may extend over an entire continent or be limited to a small area (referred to as 'local datum'). This project used the North American Datum of 1983 (NAD83) (ASP 1984).

Density. Density is the relationship between the area covered by the vegetation and the total area of a polygon in which the community is found. The USGS-NPS Vegetation Mapping Program uses a series of arbitrarily defined density classes to separate vegetation units: Closed/Continuous > 60 %, Discontinuous 40-60%, Dispersed 25-40%, Sparse 10-25%, Rare 2-10%. Compare with Pattern and Height.

Diagnostic Species. A species generally considered to indicate (i.e., diagnose) a specific set of environmental conditions. For example, the presence of *Vaccinium stamineum* var. *stamineum* (gooseberry) beneath a canopy of chestnut oak, black oak, and Virginia pine indicates that the site is

dry. The trees can inhabit a wide range of sites, wet to dry, but the gooseberry understory is the indicator of a drier habitat. Sometimes also called Indicator Species (FGDC 1997).

Dichotomous Field Key. A document that identifies plant associations or map classes on the basis of pairs of exclusive characteristics such as "forested" versus "non-forested". This key is an important product of each vegetation-mapping project. Also known as Vegetation Field Key and Vegetation Key.

Digital Orthophoto Quadrangle (DOQ). A USGS digital product derived from high altitude aerial photography. Each DOQ is rectified and registered to locations on the earth and covers the same area as a 7.5 minute quad. These are often used as base maps to register photointerpreted data. See also Quarter Quadrangle.

Digital Raster Graphic (DRG). A scanned image of a paper USGS topographic quadrangle map. The geographic information is georeferenced to the UTM projection with the same accuracy and datum as the original map. The minimum scanning resolution is 250 dots per inch.

Digitize. The process of converting lines on a map or image into a computer file. The basic technique involves tracing a line with a device connected to a computer that sends a stream of x-y coordinates corresponding to the traced line into a computer file. Synonymous with Automation.

Division. The highest level in the NVCS hierarchy, separating the earth's surface into vegetated and non-vegetated categories (FGDC 1997). (See NVCS).

Dominance. The extent to which a given species or life form dominates in a community because of its size, abundance or cover. The ecological assumption is that dominant species can affect the fitness of associated species (FGDC 1997).

Dominant Life Form. An organism, group of organisms, or taxon that by its size, abundance, or coverage exerts significant influence upon an association's biotic and abiotic conditions (FGDC 1997).

Ecological Groups. Non-NVCS categories of vegetation based on plant assemblages, physical environments, and dynamic processes useful for conservation planning. These groups are classified on total floristic composition, physiognomy (vertical structure), distribution (horizontal structure), physical environment (slope, rainfall), chemical variables (soil pH), and disturbance regimes. Some factors are difficult to measure directly, and must be inferred from knowledge of species ecology, spatial patterns, and ecological processes.

Edge Distortion. In reference to aerial photographs, lens distortion increases with distance from the center of the photograph. Because of this, photointerpreters work only with the center third of each aerial photograph.

Error. The numeric distance of results of observations, computations, or estimates from the values that are accepted as being true. Also refers to the misclassification of thematic data. Contrast with Accuracy.

Error Matrix. See Contingency Table.

Existing Vegetation. The plant species existing at a location at the present time. The USGS-NPS Vegetation Mapping Program

classifies and maps existing vegetation. Contrast with Potential Vegetation

Federal Geographic Data Committee (FGDC). Coordinates the development of the National Spatial Data Infrastructure (NSDI). The NSDI encompasses policies, standards, and procedures for agencies to produce and share geographic data. The 17 federal agencies that make up the FGDC are developing the NSDI in cooperation with state, local, and tribal governments, the academic community, and the private sector.

Field Reconnaissance. Preliminary field visits by photointerpreters and vegetation ecologists to gain an overview of the vegetation of the project area and how it relates to the NVCS.

Flight Line. A line connecting the principal points of sequential vertical aerial photographs. Designated on the film as 'flight line number – photo number' (ASP 1984).

Floristics. The kinds, number and distribution of plant species in a particular area.

Formation. A level in the NVCS hierarchies that represents vegetation types sharing a definite physiognomy or structure within broadly defined environmental factors, relative landscape positions, or hydrologic regimes (Grossman et al. 1998).

Frequency. The number of occurrences of an item of interest.

Georeference. The process of converting a map or image into real-world coordinates. A non-georeferenced map or image is said to be in 'digitizer-inches' or 'scanner-inches', i.e., it has no real-world coordinates.

Geographic Information System (GIS).

An organized database of geographically referenced information (ESRI 1994).

Global Positioning System (GPS). A system of satellites, ground receiving stations and handheld receivers that allow accurate location of features on the earth's surface. GPS receivers are used to locate field relevés, reconnaissance points, and accuracy assessment points.

Gradsect. Gradient directed transect sampling. The gradsect sampling design is intended to provide a description of the full range of biotic variability (e.g., vegetation) in a region by sampling along the full range of environmental variability. This approach is based on the distribution of vegetation along environmental gradients. Transects that contain the strongest environmental gradients in a region are selected in order to optimize the amount of information gained in proportion to the time and effort spent during the vegetation survey (Grossman et al. 1994).

Ground photograph. An image recorded with the photographer standing on the ground (See Aerial Photography).

Ground truth. The process of taking aerial photographs into the field to see how particular photographic signatures compare with the vegetation on the ground.

Group. The level in the NVCS hierarchies based on leaf characters and identified and named in conjunction with broadly defined macroclimatic types to provide a structural-geographic orientation (Grossman et al. 1998).

Habitat. The combination of environmental or site conditions and ecological processes influencing a plant community.

Habitat Type. 1. A collective term for all parts of the land surface supporting, or capable of supporting, the same kind of climax plant association (Daubenmire 1978). 2. An aggregation of land areas having a narrow range of environmental variation and capable of supporting a given plant association (Gabriel and Talbot 1984).

Hectare. A metric unit of measure equal to 10,000 m² or approximately 2.471 acres.

Height. Height of the overstory of a plant community. One of the physiognomic modifiers classified in the USGS-NPS Vegetation Mapping Program. Vegetation polygons are attributed by height class: < 0.5 m, 0.5-2 m, 2-5 m, 5-15 m, 15-35 m, 35-50 m, >50 m. Compare with Density and Pattern.

Indicator Species. See Diagnostic Species.

Infrastructure. Human-built systems that include structures such as roads and bridges, water supply systems, and electric, gas or telephone lines.

Integrated Taxonomic Information System (ITIS). A comprehensive, standardized reference for the scientific names, synonyms and common names for all the plants and animals of North America and the surrounding oceans. This database is accessible over the Internet (<http://www.itis.usda.gov/>). The PLANTS database is an important ITIS partner providing plant taxonomic information to ITIS.

Land Cover Classification.

A classification of the cultural, physical, and vegetation features that cover the earth, commonly used with remote sensing technology. The Anderson Classification System is a land cover/land use classification.

Vegetation classification is a subset of land cover classification.

Land Use Classification. A classification of the earth's surface that defines the human use the land is providing. Commonly used with remote sensing technology, and usually combined with land cover classification. Natural vegetation may be classified as "vacant", "forest", or "grazing".

Large-scale. Refers to a map or image with a large-scale denominator (e.g., 1:100,000). Large-scale maps cover a broad area, are usually low in detail, and images usually have low resolution (e.g., 30m per pixel).

Look-Up Table (LUT). A computer file that is a list of standard elements that may be entered in a field in the database. In the context of these vegetation-mapping projects, LUT relates the elements of one classification to another in a crosswalk. The values of a map classification could be related to the associations of the NVCS in a park project.

Map Accuracy. A measure of the maximum error allowed in horizontal location and elevation on maps. For example, the USGS map accuracy standards for 1:24,000-scale maps are that 90% of well-defined objects should appear within 40 feet (12.2 meters) of their true location. See United States National Map Accuracy Standards.

Map Attribute. See Attribute.

Map Class. Plant communities and non-vegetated elements that can be discerned on an aerial photograph. If individual plant associations cannot be distinguished on an aerial photograph, map classes lumping related plant associations must be developed. For example, at Devils Tower National Monument there were five associations in the

Ponderosa Pine Woodland Alliance, but it was necessary to create two ponderosa pine map classes because the associations could not be distinguished on the photography. Also known as Map Unit.

Map Code. The map class code number related to the map class. For example, map class Cinder Sparse Mosaic has a map code of 1.

Map Scale. The relationship between a distance portrayed on a map and the same distance on the earth's surface (Dana 1999). A scale of 1 inch = 1000 feet can also be expressed as 1:12,000 (i.e., 1 inch on the map equals 12,000 inches on the earth). When a map is reproduced in a different size, the scale reference (1:12,000) is no longer valid but the scale bar on the map is still valid.

Map Projection. A systematic conversion of locations on the Earth's surface from spherical coordinates to planar coordinates (ESRI 1994).

Map Unit. See Map Class.

Map Validation. The process of field checking photointerpretation. This step is completed prior to accuracy assessment.

Metadata. A text file describing how a spatial database was created. Metadata files document how the data were created, their content, quality, condition, and other characteristics. Metadata's purpose is to help organize and maintain an organization's internal investment in spatial data, provide information about an organization's data holdings to data catalogues, clearing-houses, and brokerages, and provide information to process and interpret data received through a transfer from an external source (FGDC 1997). The FGDC sets the content standards for metadata. The NBII has developed

software to aid in creating metadata and commercial software programs are also available.

Minimum Mapping Unit (MMU). The smallest area that is consistently delineated during photointerpretation. The MMU for the USGS-NPS Vegetation Mapping Program is 0.5 hectares.

Mosaic (Biology). An intermixing of plant associations in an area that has a unique photosignature but is too intricate for individual associations to be delineated. Compare with Complex.

Mosaic (Image). An image composed of an assemblage of edge-matched, overlapping aerial photographs.

National Biological Information Infrastructure (NBII). A broad, collaborative program to provide access to data and information relating to the Nation's biological resources. The NBII links diverse, high-quality biological databases, and analytical tools maintained by NBII partners in government agencies, academic institutions, nongovernmental organizations, and private industries.

National Biological Service (NBS). See Biological Resources Discipline.

National Map Accuracy Standards. See US National Map Accuracy Standards.

National Park Service (NPS). A U.S. Department of Interior agency created in 1916 and charged with preserving the natural and cultural resources of the national park system for the enjoyment, education, and inspiration of this and future generations. NPS manages the National Parks and the Inventory and Monitoring Program and works

closely with USGS to coordinate the USGS-NPS Vegetation Mapping Program.

National Vegetation Classification Standard (NVCS). The Federal Geographic Data Committee's vegetation classification model. It has been adapted to the formation level (as of June 2001); adoption of standards for finer levels is expected in the spring of 2004 with the adoption of the Ecological Society of America's 'Guidelines For Describing Associations and Alliances of the U.S. National Vegetation Classification'. Currently the U.S. National Vegetation Classification (NVC) is maintained by NatureServe and can be examined on their on-line NatureServe Explorer database (<http://www.natureserve.org/explorer/>).

Natural Heritage Programs. Operate throughout much of the western hemisphere gathering, managing, and distributing detailed information about the biological diversity found within their jurisdiction. Most programs are part of government agencies such as fish and wildlife departments, although some are run by universities or nongovernmental organizations.

Natural Resources Conservation Service (NRCS). A USDA agency that is the lead federal agency for conservation on private land and is a partner in land conservation with private land managers, conservation districts; resource conservation and development (RC&D) councils; state and local conservation agencies; state, local, and Tribal governments; rural communities; businesses; and others. The NRCS produces the nation's Soil Survey reports.

Natural Vegetation. Plant life of an area that appears to be substantially unaltered by human activities. Most existing vegetation has been subjected to some human modification, so a clear distinction between natural

and cultural vegetation may sometimes be difficult (Grossman et al. 1998).

NatureServe. A non-profit organization dedicated to developing and providing knowledge about the world's natural diversity. In cooperation with the Natural Heritage Network, NatureServe collects and develops authoritative information about the plants, animals, and ecological communities of the Western Hemisphere. NatureServe maintains databases to support the United States National Vegetation Classification Standard (NVCS) and the relevé data that it is based on. Nature-Serve's role in this project was to help develop the vegetation community classification. Formerly known as ABI (Association for Biodiversity Information).

North American Datum (NAD). The standard cartographic reference for map projections and coordinates throughout North America (see also Datum). Usually associated with a version, such as 1927 or 1983. This project used the 1983 North American datum (NAD83), which is consistent with satellite location systems. The 1983 datum uses the GRS 80 spheroid whereas the 1927 datum uses the Clarke 1866 spheroid (ESRI 1994).

Observation Point. Field data used to support map class and vegetation classification development. These points are collected during reconnaissance and verification field work.

Omission Errors. See Producer's Accuracy.

Order. The 2nd highest level in the NVCS hierarchy (FGDC 1997). An order is generally defined by dominant life form (tree, shrub, dwarf shrub, herbaceous, or non-vascular)

Ortho Image. An aerial photograph that has had the distortions common to aerial photography removed and has been registered to locations on the earth. A digital ortho image can be placed in a GIS and have other layers, such as vegetation, overlain on it. A DOQQ is an ortho image. Also sometimes called an ortho-photo.

Pattern. Describes the distribution of vegetation features across a landscape. Some examples include: Evenly Dispersed, Clumped/Bunched, Gradational/Transitional, or Alternating. Compare with Density and Height.

Photointerpretation. The art and science of identifying and delineating objects and conditions on an aerial photograph.

Photointerpretation Key. A description, often accompanied by pictures of examples, of the visual elements that make up the photographic signature of each map class.

Photointerpretation Modifiers. Codes used to describe special features that are not part of the NVCS. For example, an agency may be interested in eagle nests, beaver dams, prairie dog towns, and forest blow-down areas.

Photosignature. See Signature.

Physiognomic Modifiers. Modifiers used to describe the physiognomic structure of the vegetation found within a mapped polygon (e.g., cover, density, pattern, height).

Physiognomy. The structure and life form of a plant community (FGDC 1997).

Plant Association. See Association.

Plant Community. See Community.

PLANTS database. A database maintained by the Natural Resource Conservation Service. This database focuses on vascular plants, mosses, liverworts, hornworts, and lichens of the U.S. and its territories. The PLANTS Database includes names, checklists, automated tools, identification information, species abstracts, distributional data, crop information, plant symbols, plant growth data, plant materials information, links, references, and other information. This is the database that maintains the current list of accepted scientific names. See <http://plants.usda.gov/>.

Plot. A defined location of a certain size where the data necessary to classify the vegetation is collected. Plots are generally located non-randomly and plot size varies depending on the vegetation being sampled. See: <http://biology.usgs.gov/npsveg/fieldmethods>. Plot data are entered into a database for storage and analysis. Also referred to as Relevés.

Polygon. A multisided figure that represents area on a map. A polygon is defined by the lines that consist of the boundary and the label point within its boundary used for identification. Polygons have attributes that describe the geographic feature they represent.

Positional Accuracy. How close a point in a spatial database is to its actual location on the earth's surface. The National Map Accuracy Standard for horizontal positional accuracy at the 1:24,000 scale is 1/50 of an inch (40 feet/12.2 m) of an object's actual location.

Potential Vegetation. The vegetation that would become established if succession were completed without interference under the present climatic and edaphic conditions. Contrast with Existing Vegetation.

Precision Lightweight GPS Receiver (PLGR). A small handheld, global positioning system (GPS) receiver developed for the military and featuring anti-spoofing and anti-jamming capability.

Producer's Accuracy. The probability that a reference sample (the ground data) has been classified correctly, also known as error of omission. This quantity is computed by dividing the number of samples that have been classified correctly by the total number of reference samples in that class (Storey and Congalton 1986). Compare with User's Accuracy.

Projection. A two-dimensional representation of data located on a curved surface. Projections always involve distortion, so the cartographer must choose which characteristics (distance, direction, scale, area, or shape) will be emphasized at the expense of the other characteristics (Snyder 1982). In this project, all spatial data use the Universal Transverse Mercator (UTM) coordinate system that is based on the transverse mercator projection applied between 84 degrees north and 80 degrees south latitude.

Quadrangle. A USGS 7.5 minute topographic map.

Quarter Quad(rangle). A map or image that includes ¼ of a 7.5-minute quadrangle map. Quarter quadrangles are organized in geographic quadrants of the original map: northeast, northwest, southeast, and southwest.

Rectify. To remove distortions from aerial photographs in the process of transferring interpreted photographs into a spatial database. Distortions on photographs are due to topographic relief on the ground, radial distortion in the geometry of the aerial photog-

raphy, tip and tilt of the plane, and differences in elevation of the airplane from its nominal scale. This process may be separate or included in the registration process, depending on the technology used.

Reference Data. The field data that is collected for the accuracy assessment.

Register. The process of relating objects on an aerial photograph to the surface of the earth. This is necessary to be able to place vegetation data in a GIS with other spatial data such as roads, topography, or soils. This process may be separate or may be included in the rectification process, depending on the technology used. See also Transfer.

Relevé. See Plot.

Sample Data. Sample data are the map classes that were photo-delineated as occurring on the vegetation map. The sample data is compared to the reference data (see reference data) to compute map accuracy.

Scale. The relationship between a distance portrayed on a map and the same distance on the Earth (Dana 1999). A map scale can be defined by a fraction (e.g., 1 unit on map / 12,000 units on ground) or by a graphic scale bar.

Signature. The unique combination of color, texture, pattern, height, physiognomy, and position in the landscape used by photointerpreters to identify map classes on an aerial photograph. Or, characteristics of an item on a photograph by which the item may be identified (ASP 1984). Also referred to as Photosignature.

Small-scale. Refers to a map or image with a relatively small-scale denominator (e.g. 1:1,000). Small-scale maps cover a small

area, have fine detail, and the images have high resolution (e.g. 0.5m per pixel).

Spatial. Refers to features or phenomena distributed in geographic space and having physical, measurable dimensions.

Special Modifiers. See Photointerpretation Modifiers.

Stratum. A horizontal layer of vegetation. A stratum may be defined by the life form of the vegetation (tree, shrub, herbaceous), its relative position in the community (understory) or its actual height.

Structure (Vegetation). The spatial distribution pattern of life forms in a plant community, especially with regard to their height, abundance, or coverage within the individual layers. Synonymous with Physiognomy.

Subclass. The level in the NVCS hierarchies based on growth form characteristics (Grossman et al. 1998).

Subgroup. The level in the NVCS hierarchies that divides each group into either a "natural/semi-natural" or "cultural" (planted/cultivated) subgroup (Grossman et al. 1998).

The Nature Conservancy (TNC). A non-profit conservation organization founded in 1951. Working with communities, businesses and people, TNC protects millions of acres of valuable lands and waters worldwide. TNC was the original caretaker of the National Vegetation Classification (NVC), but those responsibilities have been spun off to NatureServe. TNC no longer has an active role with the USGS-NPS Vegetation Mapping Program.

Thematic Accuracy. The correctness of the map classes in relation to the vegetation on the ground. This is determined through standardized accuracy assessment procedures. The program standard is 80% accuracy for each map class within 90% confidence intervals. See Accuracy Assessment, Producer's Accuracy, and User's Accuracy.

Thematic Map. A map that displays the spatial distribution of a single attribute or a specific topic, such as land-cover and land-use classes.

Topology. The explicit definition of how map features represented by points, lines and areas are related. Specifically, accounting for issues of connectivity and adjacency of features.

Topographic Quads. USGS paper maps showing the topography of an area as well as roads, railroads, water bodies, buildings, urban developments, and wetlands. These come in a variety of scales, but commonly refer to 1:24,000-scale 7.5-minute quads. Informally referred to as topo quads.

Transfer. The process of entering data from interpreted aerial photo overlays into a digital database. The data is usually registered and rectified into real-world geographic coordinates. This process varies depending on the type of technology used. See also Transformation.

Transform(ation). The process of converting coordinates (map or image) from one coordinate system to another. This involves scaling, rotation, translation, and warping (images) (ESRI 1994).

Transition Zone. An area where the vegetation composition and structure is intermediate between two associations. The tran-

sition zone may be narrow as associations abruptly change due to a significant change in a major habitat factor, such as a cliff, or it may be broad when the physical environment changes gradually. Transition zones may be challenging to classify or map.

Type. A generic term that can mean any vegetation level in the NVCS, whether an association, alliance, formation, etc, or even a combination of levels. It is a vague but useful term. It is correctly used when the focus is not on a specific unit of vegetation, but rather when used loosely to explain some other point (e.g., "We do not have a good grasp of how vegetation types at Acadia link to the map classes."). Also known as Vegetation Type.

United States Geological Survey (USGS). Established in 1879, the USGS is the natural science agency for the Department of the Interior. The USGS is one of the host agencies, along with the National Park Service, for the USGS-NPS Vegetation Mapping Program.

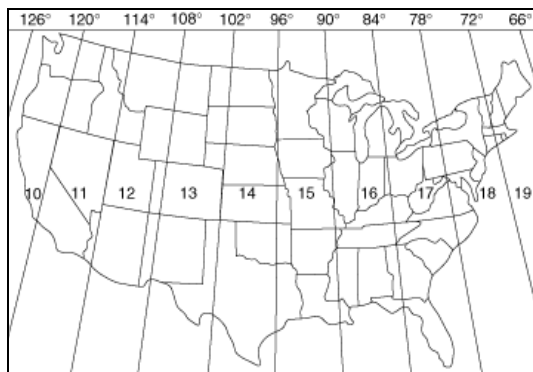
United States National Map Accuracy Standards. Defines accuracy standards for published maps, including horizontal and vertical accuracy, accuracy testing method, accuracy labeling on published maps, labeling when a map is an enlargement of another map, and basic information for map construction as to latitude and longitude boundaries. The table below shows the standard for some common map scales. Note that the conversion of paper maps into digital data usually creates additional error.

| Scale | Engineering Scale | Accuracy Standard |
|---------|-------------------|-------------------|
| 1:1,200 | 1"=100' | +/- 3.33 feet |
| 1:2,400 | 1"=200' | +/- 6.67 feet |
| 1:4,800 | 1"=400' | +/- 13.33 feet |
| 1:9,600 | 1"=800' | +/- 26.67 feet |

| | | |
|-----------|-------------|-----------------|
| 1:10,000 | | +/- 27.78 feet |
| 1:12,000 | 1"=1000' | +/- 33.33 feet |
| 1:24,000 | 1"=2000' | +/- 40.00 feet |
| 1:63,360 | 1"=one mile | +/- 105.60 feet |
| 1:100,000 | | +/- 166.67 feet |

Universal Transverse Mercator (UTM).

A map coordinate system (not a map projection) that is defined by the Transverse Mercator projection which has a set of zones defined by a central meridian as shown in the figure below for the United States (ESRI 1994):



User's Accuracy. In assessing the thematic accuracy of a vegetation map, the probability that a sample from the mapped data actually represents that category on the ground, also known as error of commission. This quantity is computed by dividing the number of correctly classified samples by the total number of samples that were classified as belonging to that category (Story and Congalton 1986). Compare with Producer's Accuracy.

Vector Data. Spatial (usually digital) data that consists of using coordinate pairs (x, y) to represent locations on the earth. Features can take the form of single points, lines, arcs or closed lines (polygons).

Vegetation. The plant cover over an area (FGDC 1997).

Vegetation Characterization. The detailed description of a plant association's diagnostic and dominant species, structure, and/or ecological processes. See: <http://biology.usgs.gov/npsveg/agfo/descript.pdf>

Vegetation Classification. The process of categorizing vegetation into recognizable and consistent elements. Also a document that lists and organizes the vegetation communities in an area. An example of a vegetation classification can be found at <http://biology.usgs.gov/npsveg/agfo/methods.pdf> classification.

Vegetation Community.

See Community.

Vegetation Description.

See Vegetation Characterization.

Vegetation (Field) Key.

See Dichotomous Field Key.

Vegetation Mapping. The process of identifying, classifying, and locating vegetation communities using real world coordinates.

Vegetation Structure. See Structure.

Vegetation Type. See Type.

Vertical Aerial Photography.

See Aerial Photography.

Wetland. A community or landscape type that is characterized by either hydric soils or hydrophytic plants or both. A wetland may be vegetated or non-vegetated.

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APPENDIX A

A. CD-Rom Readme Text and CD-Rom

The following is the text of the Readme.doc document for the CD-Rom that accompanies this report. This CD-Rom contains all coverages and GIS data developed for the SUCR vegetation map, databases for vegetation classification relevés and accuracy assessment observations, field photos, report files, and associated metadata. The associated metadata describes the attributes in all of the coverages and databases. We also include a list of appropriate citations below each of the coverages or databases to be used when citing these sources.

The files are arranged on the CD-Rom as follows:

Readme.doc – This file

1. Ancillary_Data Folder - This folder contains 4 subfolders with information on the park, project, and imagery boundary files. Each subfolder contains a coverage in Arc/Info export format (.e00), a shape file, a coverage, and associated metadata:
 - a. Flightline_bndry- Flightline boundaries used to develop the aerial photography
Citation:
U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Flight Line Coverage: Sunset Crater Volcano National Monument. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - b. Park_bndry- Boundary of Sunset Crater Volcano National Monument
Citation:
Flagstaff Area National Monuments. 2004. Boundary: Sunset Crater Volcano National Monument, AZ. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - c. Proj_bndry- Boundary for vegetation map for Sunset Crater Volcano National Monument
Citation:
U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Project Boundary: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - d. Quad_Doqq_bndry-Boundary of the USGS topographic quadrant maps for Sunset Crater Volcano National Monument
Citation:
U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Boundary: Flagstaff Area National Monuments USGS Quadrangles and DOQQs. A digital spatial database (ArcInfo). U.S. Geological Survey.
2. Basemap folder – This folder contains the MrSid compressed mosaic of the DOQQs and associated metadata for Sunset Crater National Monument. The MrSid images can be viewed as images in ArcView using the MrSid extension.
Citation:
U.S. Geological Survey. 2004. DOQQ Basemap: Sunset Crater Volcano National Monument. Digital orthophotoquads. U.S. Geological Survey.

3. Ground Photos (.tif/.jpeg) - This folder contains photos for each relevé collected for the vegetation classification. Each photo is listed as “SC-***a/b/c” where the SC stands for Sunset Crater, the *** indicates the relevé number, and either a, b, or c is listed after the prefix corresponding sequentially to the number of photos taken at each relevé point. For example, at relevé number SC-032 two photos were taken and are listed as SC-032a and SC-032b. For additional information on the aspect and time of the photo taken at each relevé refer to the Vegetation Relevé Database described below.
4. Map_Demo – This folder contains an ArcView project file (.apr), associated data that was used to create the final vegetation map, graphics associated with printing the vegetation map, and a readme.txt file. To open the project, a copy of this folder must be placed on your hard drive. You will also need the ArcPress extension. Start ArcView and then navigate to the project file (Sucr_demo.apr). Further information can be found in the included readme.txt. To print the vegetation map, a graphic of the map can be found under the Vegetation_Map folder, under the Graphics folder, and in the Map_Demo folder. In the HP_RTL folder an ArcPress extension (sucr_veg.rtl) will allow you to directly print the map layout to a plotter. In the MS_Bitmap folder a graphic (sucr_veg.bmp) will also allow you to print out the map.
5. Project_Report – This folder contains the entire final project report (SUCR_Final_Report.pdf) in an Adobe Acrobat format.
6. Vegetation_Data – This folder contains all the spatial data (final vegetation GIS cover including a vegetation map clipped to the park boundary, observation points, aspen cover, accuracy assessment points, classification relevé points, and off road vehicle cover) and databases (Vegetation Relevé Database and Accuracy Assessment Database) used to create the final vegetation map as well as associated metadata.
 - a. Accuracy Assessment
 1. Database- Microsoft access database named SUCR_AAdatabase.mdb with accuracy assessment data
Citation:
Hansen, M. and K. Thomas. 2004. Sunset Crater Volcano National Monument: Accuracy Assessment. A MS Access database. U.S. Geological Survey.
 2. Metadata-All associated metadata for the spatial data and database
 3. Spatial data- A coverage and shapefile of the accuracy assessment points used in the accuracy assessment analysis
 4. sucr_aa_pts.e00-An Arc/Info export format (.e00) of the accuracy assessment points
Citation:
Dale, B., M. Hansen, and K. Thomas. 2004. Accuracy Assessment Points: Sunset Crater Volcano National Monument. A digital spatial database (ArcInfo). U.S. Geological Survey.
 - b. Aspen_Map
 1. Metadata-Associated metadata for the spatial data

2. Spatial data- A coverage and shapefile of the occurrence of aspen in the Sunset Crater Vegetation Mapping Project
3. sucr_aspen.e00-An Arc/Info export format (.e00) of the cover of aspen in the project boundary

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Aspen Coverage: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

c. Clip_Veg

1. Metadata- Associated metadata for the spatial data
2. Spatial data- A coverage and shapefile of the vegetation map clipped to the Sunset Crater Volcano National Monument boundary
3. sucr_clip_veg.e00-An Arc/Info export format (.e00) of the cover of vegetation map clipped to the Sunset Crater Volcano National Monument boundary

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Clipped Vegetation Coverage: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

d. Observation_Points

1. Metadata- Associated metadata for the spatial data
2. Spatial data- A point coverage and shapefile of the observation points used to help with the photointerpretative work
3. sucr_obs.e00- An Arc/Info export format (.e00) of the observation points collected in the field to help with the photointerpretative work

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Observation Point Coverage: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

e. OHV_Map

1. Metadata- Associated metadata for the spatial data
2. Spatial data- A point coverage and shapefile of the off highway vehicle tracks are embedded within and can be identified in the coverage or shapefile relational table.
3. sucr_obs.e00- An Arc/Info export format (.e00) of the area where off highway vehicle tracks were evident in the project area. Areas with no evident tracks are embedded within and can be identified in the coverage or shapefile relational table

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Off Highway Vehicle Use: Sunset Crater Volcano National Monument. A digital spatial database (ArcInfo). U.S. Geological Survey.

f. Releve_Plots

1. Database- Microsoft access database named SUCR_FieldReleve_data-base.mdb with all the information collected in the field at each classification relevé

Citation:

Hansen, M. and K. Thomas. 2004. Field Relevé Plots: Sunset Crater Volcano National Monument. A MS Access database. U.S. Geological Survey.

2. Metadata- Associated metadata for the database and spatial data
3. Spatial data- A coverage and shapefile of the classification relevés
4. sucr_releve.e00-An Arc/Info export format (.e00) of the cover of classification relevé points sampled in the Sunset Crater project boundary

Citation:

Hansen, M. and K. Thomas. 2004. Field Relevé Plots: Sunset Crater Volcano National Monument Vegetation Mapping Project. A digital spatial database (ArcInfo). U.S. Geological Survey.

g. Vegetation_Map

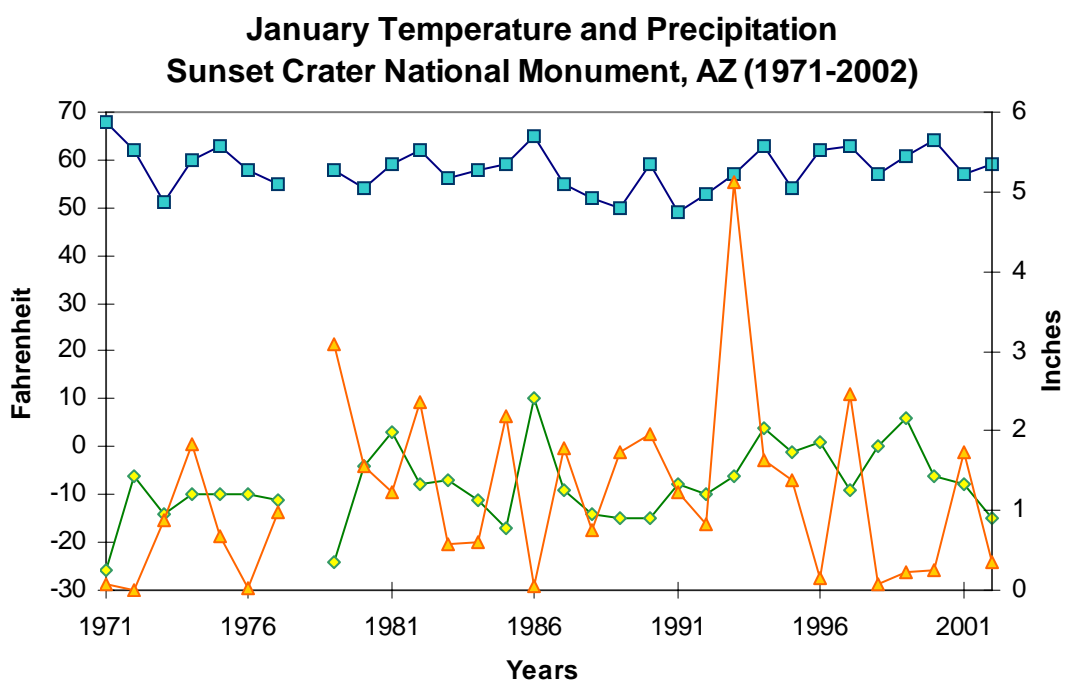
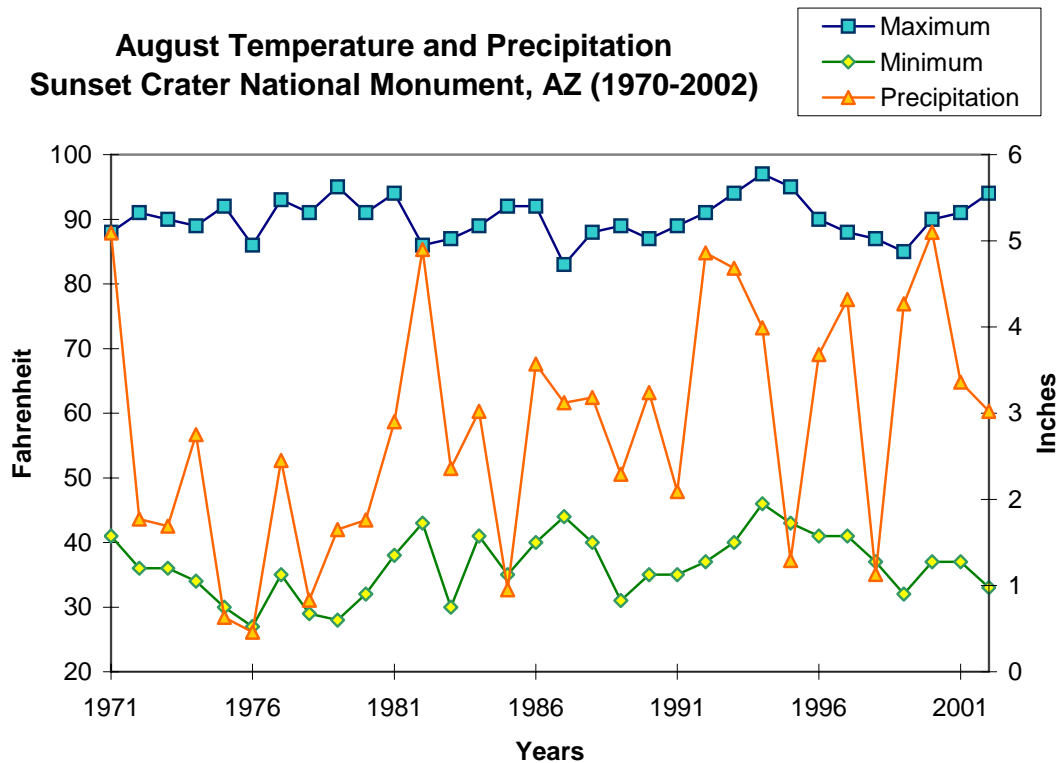
1. Metadata- Associated metadata for the spatial data
2. Spatial data- A coverage and shapefile of the vegetation map for the Sunset Crater Volcano National Monument and the project environs
3. sucr_veg.e00-An Arc/Info export format (.e00) of the cover of the vegetation map coverage

Citation:

U.S. Bureau of Reclamation Remote Sensing and GIS Group. 2004. Sunset Crater Volcano National Monument Vegetation Map. A digital spatial database (ArcInfo). U.S. Geological Survey.

APPENDIX B

B. Precipitation and Temperature Averages for Sunset Crater Volcano National Monument (August and January 1971-2002)



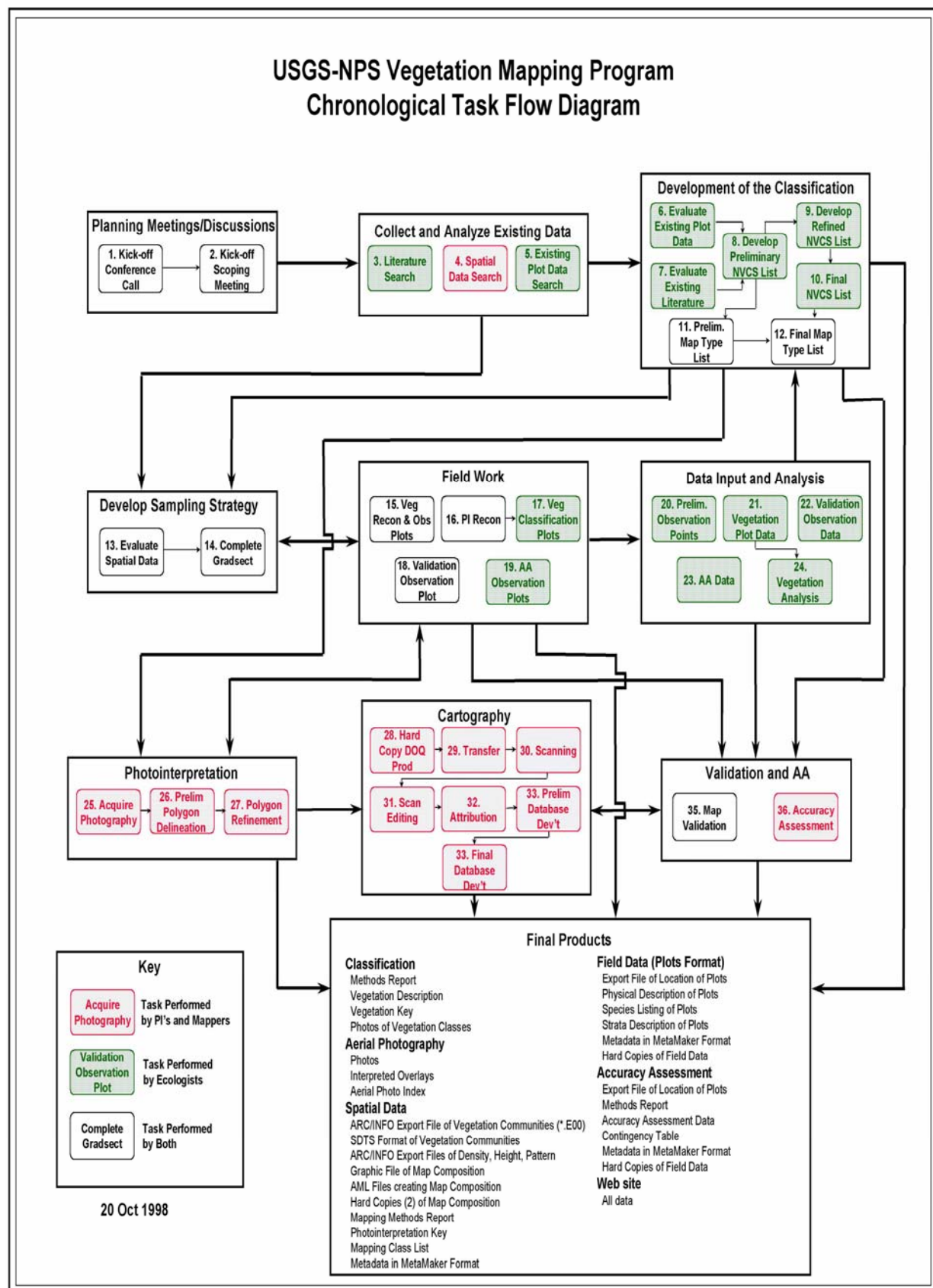
Precipitation data from www.ncdc.noaa.gov/ol/climate/online/coop-precip.html
for the Sunset Crater reporting station. (Internet Access January 2002)

Temperature data from www.ncdc.noaa.gov/ol/climate/climatedata.html for the Flagstaff area.
(Internet Access January 2002)

APPENDIX C

C. Flowchart of USGS-NPS National Parks Vegetation Mapping Program

(Created by Tom Owens)



APPENDIX D

D. Photointerpretation Observations, Classification Relevés, and Accuracy Assessment Observations Forms

NATIONAL PARK VEGETATION MAPPING PROGRAM: PHOTOINTERPRETATION OBSERVATION FORM

IDENTIFIERS/LOCATORS

| | |
|---|--------------------------------------|
| Plot Code _____ | Polygon Code _____ |
| Provisional Community Name _____ | |
| State ____ | Park Name _____ Park Site Name _____ |
| Quad Name _____ | Quad Code _____ |
| GPS file name _____ Field UTM X _____ m E Field UTM Y _____ m N | |
| <i>please do not complete the following information when in the field</i> | |
| Corrected UTM X _____ m E Corrected UTM Y _____ m N UTM Zone _____ | |
| Survey Date _____ Surveyors _____ | |

ENVIRONMENTAL DESCRIPTION

| | | |
|----------------------------|-------------|--------------|
| Elevation _____ | Slope _____ | Aspect _____ |
| Topographic Position _____ | | |
| Landform _____ | | |

| | | |
|-------------------------|-----------------------------------|------------------------------------|
| Cowardian System | Hydrologic Regime | Salinity/Halinity Modifiers |
| ___ Upland | <u>Non-Tidal</u> | ___ Saltwater |
| ___ Riverine | ___ Permanently Flooded | ___ Brackish |
| ___ Palustrine | ___ Saturated | ___ Freshwater |
| ___ Lacustrine | ___ Semipermanently Flooded | |
| | ___ Temporarily Flooded/Saturated | |
| | ___ Intermittently Flooded | |
| | ___ Seasonally Flooded | |

| | |
|-------------------------|---|
| Environmental Comments: | Unvegetated Surface: <i>(please use the cover scale below)</i> ___ Bedrock ___ Litter, duff ___ Wood (> 1 cm) ___ Large rocks (cobbles, boulders > 10 cm) ___ Small rocks (gravel, 0.2-10 cm) ___ Sand (0.1-2 mm) ___ Bare soil ___ Other: _____ |
|-------------------------|---|

VEGETATION DESCRIPTION

| Leaf phenology (of dominant stratum) | Leaf Type (of dominant stratum) | Physiognomic class | Cover Scale for Strata & Unvegetated Surface | Height Scale for Strata |
|---|---|---|--|---|
| <u>Trees and Shrubs</u> ___ Evergreen ___ Cold-deciduous ___ Drought-deciduous ___ Mixed evergreen - cold-deciduous ___ Mixed evergreen - drought-deciduous <u>Herbs</u> ___ Annual ___ Perennial | ___ Broad-leaved ___ Needle-leaved ___ Mixed broad-leaved/Needle leaved ___ Microphyllous ___ Graminoid ___ Forb ___ Pteridophyte | ___ Forest ___ Woodland ___ Shrubland ___ Dwarf Shrubland ___ Herbaceous ___ Nonvascular ___ Sparsely Vegetated | 01 5% 02 10% 03 20% 04 30% 05 40% 06 50% 07 60% 08 70% 09 80% 10 90% 11 100% | 01 <0.5 m 02 0.5-1m 03 1-2 m 04 2-5 m 05 5-10 m 06 10-15 m 07 15-20 m 08 20-35 m 09 35 - 50 m 10 >50 m |

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

| Strata | Height | Cover Class | Dominant species (mark any known diagnostic species with a *) | Cover Class |
|---|--------|-------------|--|-------------------------|
| T1 Emergent | _____ | _____ | _____ | |
| | | | _____ | |
| | | | _____ | |
| T2 Canopy | _____ | _____ | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| T3 Sub-canopy | _____ | _____ | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| S1 Tall shrub | _____ | _____ | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| S2 Short Shrub | _____ | _____ | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| S3 Dwarf-shrub | _____ | _____ | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| H Herbaceous | _____ | _____ | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| | | | _____ | |
| N Non-vascular | _____ | _____ | _____ | |
| | | | _____ | |
| V Vine/liana | _____ | _____ | _____ | |
| | | | _____ | |
| E Epiphyte | _____ | _____ | _____ | |
| | | | _____ | |
| <i>please see the table on the previous page for height and cover scales for strata</i> | | | | |
| Other Comments | | | | Cover Scale for Species |
| | | | | 01 <1% |
| | | | | 02 1-5% |
| | | | | 03 5-25% |
| | | | | 04 25-50% |
| | | | | 05 50-75% |
| | | | | 06 75-100% |

CLASSIFICATION RELEVÉ FORM

SURVEY AND SITE INFORMATION

| | | | |
|---|---------------------|--|----------------|
| Park Name: _____ | | Date: _____ | |
| Surveyors: _____ | | | |
| Plot Code: _____ | | | |
| Provisional Alliance/Association Name: _____ | | | |
| Zone 12 | | Datum NAD 83 | |
| USGS Quad: _____ | 7.5 or 15' | Environ-Code: _____ | |
| Air Photo #: _____ | Polygon Code: _____ | | |
| UTM E: _____m | UTM N: _____m | Way Point: _____ | |
| Error =+/- _____ | | | |
| Landowner(check one): NPS _____ Forest Service _____ Private(owner if known) _____ State Lands: Game and Fish _____ | | | |
| Plot length: _____ m | | Plot width: _____ m | |
| | | Plot Shape: (square, rectangle, triangle, circle) | |
| for 400m ² | | Circle Diameter=35.6m for 1000m ² , Diameter=22.6 | |
| Directions to Plot: _____ | | | |
| _____ | | | |
| _____ | | | |
| Plot Photos (Y/N): _____ | | Roll #: _____ | Frame #: _____ |
| Date: _____ | | Time: _____ | |
| Direction: _____ | | | |

ENVIRONMENTAL DESCRIPTION

| | | | |
|--|--|--|-------------------------------------|
| Elevation: _____ (m.) | Slope: _____ % | Aspect: _____ | |
| Topographic position: _____ Landform: _____ (enter number from Code Sheet) | | | |
| Community Type: _____ (Wetland(W) or Upland(U)) (if W then) | | | |
| <input type="checkbox"/> Estuarine | <input type="checkbox"/> Semipermanently Flooded | <input type="checkbox"/> Permanently Flooded | <u>Salinity/Halinity</u> |
| <input type="checkbox"/> Riverine | <input type="checkbox"/> Seasonally Flooded | <input type="checkbox"/> Permanently Flooded-tidal | <u>Modifiers:</u> |
| <input type="checkbox"/> Palustrine | <input type="checkbox"/> Saturated | <input type="checkbox"/> Tidally Flooded | <input type="checkbox"/> Saltwater |
| <input type="checkbox"/> Laustrine | <input type="checkbox"/> Temporarily Flooded | <input type="checkbox"/> Artificially Flooded | <input type="checkbox"/> Brackish |
| | <input type="checkbox"/> Intermittently Flooded | | <input type="checkbox"/> Freshwater |

VEGETATION DESCRIPTION

Vegetation Group: _____ (from the three columns below)

| Leaf phenology: | Leaf Type: | Physiognomic class: |
|-------------------------------------|---------------------------------|-----------------------------------|
| <u>Trees and Shrubs</u> | 1_Broad-leaved | 1_Forest |
| 1_Evergreen | 2_Needle-leaved | 2_Woodland |
| 2_Cold-deciduous | 3_Microphyllous | 3_Shrubland |
| 3_Drought-deciduous | 4_Graminoid | 4_Dwarf shrubland |
| 4_Mixed evergreen-cold-deciduous | 5_Broad-leaved herbaceous | 5_Herbaceous (grassland and forb) |
| 5_Mixed evergreen drought-deciduous | 6_Pteridophyte | 6_Nonvascular |
| <u>Herbs</u> | 7_Mixed broad and needle-leaved | 7_Sparsely vegetated |
| 6_Annual | 8_Extremely xeromorphic | |
| 7_Perennial | 9_Hydromorphic | |

Additional Comments:

**USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument**

Plot # _____ Date: _____

Cover Class Intervals: 1(<1%), 2(1-5%), 3(>5-10%), 4(>10-25%), 5(>25-50%), 6(50-75%), 7(>75%)

G=Ground(<0.5m), S-Shrub(0.5-3.0m), T-Tree(>3.0m)

Layer

[illegible]

(Fill data only once per field plot!)

Total Vegetation Cover(Class): ____ Total Tree ____ Total Shrub ____ Total Ground ____ Total Non-native ____
% ____

Cover Scale for Strata, Sensitive Species, Exotics, Biotic Surfaces and Unvegetated Surface:

| | | | | | | | |
|----|-------|----|---------|----|---------|----|------|
| 01 | <1% | 03 | >5-10% | 05 | >25-50% | 07 | >75% |
| 02 | >1-5% | 04 | >10-25% | 06 | >50-75 | | |

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

| Unvegetated Surface | Bare Soil | Sand (0.1-2mm) | Gravel (2mm-6.4cm) | Cobble (6.4-19cm) | Stone (>19-61cm) | Boulder (>61 cm) | Bedrock | Litter, duff | Biotic Crust (cryptograms, moss, lichens) |
|---------------------|-----------|----------------|--------------------|-------------------|------------------|------------------|---------|--------------|---|
| Cover Class | | | | | | | | | |

| | |
|-------------------------|-------------------------|
| Environmental Comments: | Soil Taxon/Description: |
| | |

| Strata | Moss/Lichen | 0-25cm | 25-50cm | 0.5-1m | 1-3m | 3-5m | 5-10m | 10-20m | 20-30m | >30m |
|-------------|-------------|--------|---------|--------|------|------|-------|--------|--------|------|
| Cover Class | | | | | | | | | | |

Sensitive Species:

| Genus | Species | % Cover | Cover Class |
|-------|---------|---------|-------------|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Exotic Species:

| Genus | Species | % Cover | Cover Class |
|-------|---------|---------|-------------|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

DBH Table:

| Species | Diameter | Species | Diameter |
|---------|----------|---------|----------|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

3-Flagstaff Park's Code Sheet for Classification Relevés

MACRO TOPOGRAPHY

- 00 INTERFLUVE(crest, summit, ridge): linear top of ridge, hill, or mountain; elevated area between two flumes
- 01 HIGH SLOPE(shoulder slope, upper slope, convex creep slope): the top of a slope, convex
- 02 HIGH LEVEL(mesa): top of plateau
- 03 MIDSLOPE(transportational midslope, middle slope): intermediate slope
- 04 BACKSLOPE(dipslope): subset of midslopes which are steep, linear, and cliff segments
- 05 STEP IN SLOPE(ledge, terracette): nearly level shelf interrupting a steep slope, rock wall, or cliff face
- 06 LOWSLOPE(lower slope, foot slope, colluvial footslope): inner gently inclined surface at the base of a slope, concave
- 07 TOESLOPE(alluvial toeslope): outermost gently inclined surface at base of slope, commonly gentle and linear
- 08 LOW LEVEL(terrace): valley floor or shoreline representing the former position of an alluvial plain, lake or shore
- 09 CHANNEL WALL(bank): sloping side of a channel
- 10 CHANNEL BED(narrow valley bottom, gully arroyo): bed of single or braided watercourse commonly barren of vegetation
- 11 BASIN FLOOR(depression): nearly level to gently sloping, bottom surface of a basin

LANDFORM

- 20 **Rockpile**=uplands composed primarily of jointed and exfoliating granitic outcrops
- 21 **Bajada**=alluvial slopes of fans that accumulate at the base of a desert mountain or mountain canyons that are interrupted by the trenching of minor water sources
- 22 **Drainage Channel**=bottom not side slope of a drainage confined by banks or a canyon
- 23 **Valley Bottom Fill**=usually level places
- 24 **Playa**=Pleistocene dried lakebed often with some surface water
- 25 **Side Slope**=side of drainage channels
- 26 **Lower Slope**=lower better watered portion of a slope
- 27 **Mid Slope**=central portion of a slope
- 28 **Upper Slope**=the upper driest portion of a slope
- 29 **Interfluvium**=the area between small drainage channels
- 30 **Ridge**=high ground between two opposing slopes
- 31 **Slick Rock**=large exposed expanses of bedrock
- 32 **Terrace**=level or gently sloping shelf perched on a slope, often caused by down-cutting rivers
- 33 **Mesa**=level or gently sloping ground surrounded on 3 or more sides by steep down slopes and capped
- 34 **Butte**=similar to a mesa, except with a top that does not have a flat configuration
- 35 **Cliff**=very steep rock slopes
- 36 **Talus**=unsorted material resulting from mass wasting of steep mountain slopes
- 37 **Sand Dune/Sand Sheet**=large accumulations of sand, may be stable or unstable (moving)

ACCURACY ASSESSMENT OBSERVATION FORM

SURVEY AND SITE INFORMATION

| | | |
|---|---------------------|-------------|
| Park Name: <u>Sunset Crater National Monument</u> | | Date: _____ |
| Surveyors _____ | | |
| Plot Code _____ | | |
| Zone 12 | Datum NAD 83 | |
| USGS Quad _____ | 7.5 | |
| UTM E _____ m | UTM N _____ m | |
| Error =+/- _____ | | |
| Elevation _____ (m) | | |

PLEASE CIRCLE CLOSEST MAP CLASS REPRESENTING SITE:

| | |
|--|--|
| <p>Vegetation</p> <p>Apache Plume / Cinder Sparse Vegetation</p> <p>Douglas-fir Forest</p> <p>Lava Bed Sparse Vegetation</p> <p>Limber Pine Woodland</p> <p>Montane Grassland</p> <p>(also circle if appropriate: Rabbitbrush, Bonito Park)</p> <p>Pinyon – Utah Juniper / Blue Grama Woodland</p> <p>(also circle if appropriate: Sparse)</p> <p>Ponderosa Pine / Apache Plume Woodland</p> <p>(also circle if appropriate: Sparse, Pinyon)</p> <p>Ponderosa Pine / Cinder Woodland</p> <p>Ponderosa Pine / Montane Grass Mosaic</p> <p>Ponderosa Pine / Sand Bluestem Woodland</p> <p>Ponderosa Pine Invasive Herbaceous Vegetation</p> <p>Rock Outcrop and Scree Shrubland</p> <p>Wild Buckwheat – Sand Bluestem Sparse Vegetation</p> | <p>Land Use</p> <p>Cropland or pasture</p> <p>Facilities</p> <p>Recreational trails and sites</p> <p>Residential land</p> <p>Strip Mines, Quarries, Gravel Pits</p> <p>Transportation, communications and utility corridors</p> <p>Geomorphology</p> <p>Cinder Sparse Mosaic</p> <p>Lava Beds</p> |
|--|--|

CONFIDENCE: Exact Good (Some problems) Poor None that fit

Please explain all reasons for Good, Poor or None Confidence

PLEASE CIRCLE CLOSEST ASSOCIATION/ALLIANCE REPRESENTING SITE:

| | |
|--|--|
| <i>Andropogon hallii</i> Colorado Plateau Herbaceous Vegetation <i>Bouteloua gracilis</i> Herbaceous Vegetation Cinder Sparse Mosaic <i>Ericameria nauseosa</i> - <i>Pericome caudata</i> Rock Outcrop Sparse Vegetation (Local Assemblage) <i>Eriogonum corymbosum</i> Cinder Sparse Vegetation <i>Fallugia paradoxa</i> (<i>Atriplex canescens</i> , <i>Ephedra torreyana</i>) Cinder Sparse Vegetation <i>Fallugia paradoxa</i> – <i>Brickellia grandiflora</i> - <i>Holodiscus dumosus</i> Scree Shrubland (Local Assemblage) <i>Muhlenbergia montana</i> Herbaceous Vegetation. <i>Pascopyrum smithii</i> Herbaceous Vegetation <i>Pinus edulis</i> – (<i>Juniperus osteosperma</i>) / (<i>Bouteloua gracilis</i>) Woodland <i>Pinus edulis</i> / Sparse Understory Forest <i>Pinus flexilis</i> Woodland Alliance <i>Pinus ponderosa</i> / <i>Andropogon hallii</i> Woodland | <i>Pinus ponderosa</i> / <i>Bouteloua gracilis</i> Woodland <i>Pinus ponderosa</i> / Cinder Woodland. <i>Pinus ponderosa</i> / <i>Fallugia paradoxa</i> Woodland <i>Pinus ponderosa</i> / <i>Muhlenbergia montana</i> Woodland <i>Pinus ponderosa</i> - (<i>Populus tremuloides</i>) / <i>Fallugia paradoxa</i> - (<i>Holodiscus dumosus</i>) Lava Bed Sparse Vegetation <i>Pinus ponderosa</i> / <i>Rhus trilobata</i> Shrubland (Local Assemblage) <i>Pinus ponderosa</i> Wooded Invasive Herbaceous Vegetation (Local Assemblage) <i>Populus tremuloides</i> / Cinder Woodland (Local Assemblage) <i>Pseudotsuga menziesii</i> Forest Alliance <i>Pseudotsuga menziesii</i> / <i>Muhlenbergia montana</i> Forest |
|--|--|

CONFIDENCE: Exact Good (Some problems) Poor None that fit

Please explain all reasons for Good, Poor or None Confidence

APPENDIX G

G. Sunset Crater Volcano National Monument Species List

(Species list was compiled from the relevé data collected in 1999
as part of the USGS-NPS National Mapping Program)

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

| Family | Scientific Name | Common Name |
|----------------|--|---------------------------|
| Anacardiaceae | <i>Rhus trilobata</i> Nutt. | skunkbush sumac |
| Asclepiadaceae | <i>Asclepias subverticillata</i> (Gray) Vail | horsetail milkweed |
| | <i>Asclepias</i> sp. L. ¹ | milkweed |
| Asteraceae | <i>Ageratina herbacea</i> (Gray) King & H.E. Robins. | fragrant snakeroot |
| | <i>Ambrosia acanthicarpa</i> Hooke. | flatspine burr ragweed |
| | <i>Ambrosia psilostachya</i> DC. | Cuman ragweed |
| | <i>Artemisia campestris</i> ssp. <i>pacifica</i> (Nutt.) Hall & Clements | field sagewort |
| | <i>Artemisia carruthii</i> Wood ex Carruth. | Carruth's sagewort |
| | <i>Artemisia dracunculus</i> ssp. <i>dracunculus</i> L. | tarragon |
| | <i>Artemisia ludoviciana</i> Nutt. | white sagebrush |
| | <i>Artemisia</i> sp. L. | sagebrush |
| | <i>Bahia dissecta</i> (Gray) Britt. | ragleaf bahia |
| | <i>Brickellia californica</i> (Torr. & Gray) Gray | California brickellbush |
| | <i>Brickellia eupatorioides</i> var. <i>eupatorioides</i> (L.) Shinnars | false boneset |
| | <i>Brickellia grandiflora</i> (Hook.) Nutt. | Tasselflower brickellbush |
| | <i>Chaetopappa ericoides</i> (Torr.) Nesom | rose heath |
| | <i>Cirsium wheeleri</i> (Gray.) Petrak | Wheeler's thistle |
| | <i>Ericameria nauseosus</i> ssp. <i>nauseosa</i> var. <i>nauseosa</i> (Pallas ex Pursh) Nesom & Baird | rubber rabbitbrush |
| | <i>Erigeron divergens</i> Torr. & Gray | spreading fleabane |
| | <i>Erigeron flagellaris</i> Gray | trailing fleabane |
| | <i>Erigeron</i> sp. L. | fleabane |
| | <i>Gaillardia pinnatifida</i> Torr. | red dome blanketflower |
| | <i>Gutierrezia sarothrae</i> (Pursh) Britt. & Rusby | broom snakeweed |
| | <i>Helenium arizonicum</i> Blake | Arizona sneezeweed |
| | <i>Helianthus annuus</i> L. | common sunflower |
| | <i>Hymenopappus filifolius</i> var. <i>lugens</i> (Greene) Jepson | Idaho hymenopappus |
| | <i>Hymenoxys richardsonii</i> (Hook.) Cockerell | pingue rubberweed |
| | <i>Lactuca serriola</i> L. | prickly lettuce |
| | <i>Packera multilobata</i> (Torr. & Gray ex Gray) W.A. Weber & A. Löve | lobeleaf groundsel |
| | <i>Senecio</i> sp. L. | ragwort |
| | <i>Stephanomeria minor</i> (Hook.) Nutt. var. <i>minor</i> | narrowleaf wirelettuce |
| | <i>Stephanomeria</i> sp. Nutt. | wirelettuce |
| | <i>Tetradymia canescens</i> DC. | spineless horsebrush |
| | <i>Tragopogon dubius</i> Scop. | yellow salsify |
| Berberidaceae | <i>Mahonia fremontii</i> (Torr.) Fedde | Fremont's mahonia |
| Boraginaceae | <i>Cryptantha cinerea</i> var. <i>jamesii</i> Cronq. | James' cryptantha |
| | <i>Cryptantha</i> sp. Lehm. ex G. Don | cryptantha |
| | <i>Lappula occidentalis</i> (S. Wats.) Greene | flatspine stickseed |
| | <i>Lappula</i> sp. Moench | stickseed |
| | <i>Lithospermum multiflorum</i> Torr. ex Gray | manyflowered stoneseed |
| Brassicaceae | <i>Arabis fendleri</i> (S. Wats.) Greene | Fendler's rockcress |
| | <i>Arabis</i> sp. L. | rockcress |
| | <i>Descurainia incana</i> ssp. <i>incana</i> (Bernh. ex Fisch. & C.A. Mey.) Dorn | mountain tansymustard |

¹ Genera that do not include specific epithets are unique unidentified species.

USGS-NPS Vegetation Mapping Program
Sunset Crater Volcano National Monument

| | | |
|-----------------|---|--------------------------|
| | <i>Descurainia obtusa</i> (Greene) O.E. Schulz | blunt tansymustard |
| | <i>Descurainia sophia</i> (L.) Webb ex Prantl | herb sophia |
| | <i>Erysimum capitatum</i> (Dougl. ex Hook.) Greene | sanddune wallflower |
| | <i>Physaria newberryi</i> Gray | Newberry's twinpod |
| | <i>Sisymbrium altissimum</i> L. | tall tumbledmustard |
| Cactaceae | <i>Echinocereus</i> sp. Engelm. | hedgehog cactus |
| | <i>Opuntia</i> sp. P. Mill. | pricklypear |
| Capparidaceae | <i>Cleome serrulata</i> Pursh | Rocky Mountain beeplant |
| Chenopodiaceae | <i>Chenopodium album</i> L. | lambsquarters |
| | <i>Chenopodium berlandieri</i> Moq. | pitseed goosefoot |
| | <i>Chenopodium graveolens</i> Willd. | fetid goosefoot |
| | <i>Chenopodium leptophyllum</i> (Moq.) Nutt. ex S. Wats. | narrowleaf goosefoot |
| Commelinaceae | <i>Commelina dianthifolia</i> Delile | birdbill dayflower |
| Cupressaceae | <i>Juniperus deppeana</i> Steud. | alligator juniper |
| | <i>Juniperus osteosperma</i> (Torr.) Little | Utah juniper |
| | <i>Juniperus</i> sp. L. | juniper |
| Euphorbiaceae | <i>Chamaesyce fendleri</i> (Torr. & Gray) Small | Fendler's sandmat |
| | <i>Euphorbia brachycera</i> Engelm. | horned spurge |
| | <i>Euphorbia</i> sp. L. | spurge |
| | <i>Tragia ramosa</i> Torr. | branched noseburn |
| Fabaceae | <i>Alhagi maurorum</i> Medik. | camelthorn |
| | <i>Astragalus</i> sp. L. | milkvetch |
| | <i>Lotus wrightii</i> (Gray) Greene | Wright's deervetch |
| | <i>Lupinus argenteus</i> Pursh | silvery lupine |
| | <i>Lupinus</i> sp. L. | lupine |
| | <i>Oxytropis lambertii</i> Pursh | purple locoweed |
| | <i>Phaseolus angustissimus</i> Gray | slimleaf bean |
| Fagaceae | <i>Quercus gambelii</i> Nutt. | Gambel oak |
| Geraniaceae | <i>Geranium caespitosum</i> var. <i>eremophilum</i> (Woot.& Standl.) W.C. Martin & C.R. Hutchins | purple cluster geranium |
| Grossulariaceae | <i>Ribes cereum</i> var. <i>pedicellare</i> Brewer & S. Wats. | whisky currant |
| Hydrophyllaceae | <i>Phacelia crenulata</i> Torr. ex S. Wats. | cleftleaf wildheliotrope |
| | <i>Phacelia egea</i> (Greene ex Brand) Greene ex J.T. Howell | Kaweah River phacelia |
| | <i>Phacelia serrata</i> J. Voss | saw phacelia |
| | <i>Phacelia</i> sp. Juss. | phacelia |
| Lamiaceae | <i>Marrubium vulgare</i> L. | horehound |
| | <i>Monardella odoratissima</i> Benth. | mountain monardella |
| Liliaceae | <i>Yucca angustissima</i> Engelm. ex Trel. | narrowleaf yucca |
| | <i>Yucca baccata</i> Torr. | banana yucca |
| Linaceae | <i>Linum lewisii</i> Pursh | prairie flax |
| | <i>Linum neomexicanum</i> Greene. | New Mexico yellow flax |
| | <i>Linum</i> sp. L. | flax |
| Loasaceae | <i>Mentzelia pumila</i> Nutt ex Torr. & Gray | dwarf mentzelia |
| | <i>Mentzelia</i> sp. L. | blazingstar |
| Malvaceae | <i>Sphaeralcea</i> sp. St.-Hil. | globemallow |
| Nyctaginaceae | <i>Mirabilis decipiens</i> (Standl.) Standl. | broadleaf four o'clock |
| | <i>Mirabilis linearis</i> (Pursh) Heimerl | narrowleaf four o'clock |

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|----------------|--|-----------------------------|
| | <i>Mirabilis multiflora</i> (Torr.) Gray | Colorado four o'clock |
| | <i>Mirabilis</i> sp. L. | four o'clock |
| Oleaceae | <i>Forestiera pubescens</i> var. <i>pubescens</i> Nutt. | stretchberry |
| Onagraceae | <i>Gaura coccinea</i> Nutt. ex Pursh | scarlet beeblossom |
| | <i>Oenothera cespitosa</i> Nutt. | tufted evening-primrose |
| | <i>Oenothera</i> sp. L. | evening-primrose |
| Pinaceae | <i>Pinus edulis</i> Engelm. | twoneedle pinyon |
| | <i>Pinus flexilis</i> James | limber pine |
| | <i>Pinus ponderosa</i> P. & C. Lawson | ponderosa pine |
| | <i>Pseudotsuga menziesii</i> (Mirbel) Franco | Douglas-fir |
| Plantaginaceae | <i>Plantago patagonica</i> Jacq. | woolly plantain |
| Poaceae | <i>Achnatherum hymenoides</i> (Roemer & J.A. Schultes) Barkworth | Indian ricegrass |
| | <i>Agropyron desertorum</i> (Fisch. Ex Link) J.A. Schultes | desert wheatgrass |
| | <i>Andropogon hallii</i> Hack. | sand bluestem |
| | <i>Aristida divaricata</i> Humb. & Bonpl. ex Willd. | poverty threeawn |
| | <i>Aristida</i> sp. L. | threeawn |
| | <i>Bouteloua curtipendula</i> (Michx.) Torr. | sideoats grama |
| | <i>Bouteloua gracilis</i> (Willd. ex Kunth) Lag. ex Griffiths | blue grama |
| | <i>Bromus ciliatus</i> L. | fringed brome |
| | <i>Bromus rubens</i> L. | red brome |
| | <i>Bromus tectorum</i> L. | cheatgrass |
| | <i>Bromus</i> sp. L. | brome |
| | <i>Elymus elymoides</i> ssp. <i>elymoides</i> (Raf.) Swezey | squirreltail |
| | <i>Festuca arizonica</i> Vasey | Arizona fescue |
| | <i>Festuca</i> sp. L. | fescue |
| | <i>Hordeum jubatum</i> L. | foxtail barley |
| | <i>Muhlenbergia minutissima</i> (Steud.) Swallen | annual muhly |
| | <i>Muhlenbergia montana</i> (Nutt.) A.S. Hitchc. | mountain muhly |
| | <i>Muhlenbergia rigens</i> (Benth.) A.S. Hitchc. | deergrass |
| | <i>Pascopyrum smithii</i> (Rydb.) A. Love | western wheatgrass |
| | <i>Poa fendleriana</i> (Steud.) Vasey | muttongrass |
| | <i>Schizachyrium scoparium</i> ssp. <i>scoparium</i> (Michx.) Nash | little bluestem |
| Polemoniaceae | <i>Ipomopsis aggregata</i> ssp. <i>aggregata</i> (Pursh) V. Grant | scarlet gilia |
| Polygonaceae | <i>Eriogonum corymbosum</i> var. <i>aureum</i> (M.E. Jones) Reveal | crispleaf buckwheat |
| | <i>Eriogonum racemosum</i> Nutt. | redroot buckwheat |
| | <i>Eriogonum wrightii</i> Torr. ex Benth. | bastardsage |
| | <i>Eriogonum</i> sp. Michx. | buckwheat |
| Polypodiaceae | <i>Pellaea atropurpurea</i> (L.) Link | purple cliffbrake |
| | <i>Pellaea truncata</i> Goodding | spiny cliffbrake |
| Ranunculaceae | <i>Thalictrum fendleri</i> Engelm. ex Gray | Fendler's meadow-rue |
| Rosaceae | <i>Cercocarpus montanus</i> Raf. | alderleaf mountain mahogany |
| | <i>Chamaebatiaria millefolium</i> (Torr.) Maxim | fernbush |
| | <i>Fallugia paradoxa</i> (D. Don) Endl. ex Torr. | Apache plume |
| | <i>Holodiscus dumosus</i> (Nutt. ex Hook.) Heller | rock spirea |
| | <i>Purshia stansburiana</i> (Torr) Henrickson | Stansbury cliffrose |
| Rubiaceae | <i>Galium stellatum</i> Kellogg | bedstraw |
| | <i>Galium wrightii</i> Gray | Wright's bedstraw |

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| Salicaceae | <i>Populus tremuloides</i> Michx. | quaking aspen |
| Scrophulariaceae | <i>Castilleja integra</i> Gray | wholeleaf Indian paintbrush |
| | <i>Castilleja</i> sp. Mutis ex L. f. | Indian paintbrush |
| | <i>Linaria dalmatica</i> ssp. <i>dalmatica</i> (L.) P. Mill. | Dalmatian toadflax |
| | <i>Penstemon barbatus</i> (Cav.) Roth | beardlip penstemon |
| | <i>Penstemon clutei</i> A. Nels. | Sunset Crater beardtongue |
| | <i>Penstemon jamesii</i> Benth. | James' beardtongue |
| | <i>Penstemon</i> sp. Schmidel | penstemon |
| | <i>Pericome caudata</i> Gray | mountain tail-leaf |
| Solanaceae | <i>Verbascum thapsus</i> L. | common mullein |
| | <i>Physalis hederifolia</i> var. <i>fendleri</i> (Gray) Cronq. | Fendler's groundcherry |

APPENDIX H

H. Visual Guide and Descriptions of the Sunset Crater Volcano National Monument Map Classes

Introduction

This document is a guide to the photointerpretation of vegetation map classes for Sunset Crater Volcano National Monument. It provides a ground photo image for each map class as well as at least one example of each map class as it appears on the aerial photographs.

This guide does not attempt to show all variations of each map class; only the most common or significant representations are included. The descriptions should be sufficient to give the user a feel for the imagery and an understanding of the relationships between the vegetation and the map classes. This guide describes the vegetation map classes and two separate photointerpreted coverages of aspen (*Populus fremontii*) and off-highway vehicle use.

How this guide is organized

This guide describes and illustrates every vegetation map class used in the Sunset Crater vegetation mapping project and the two photointerpreted coverages with one map class per page. The images are aerial photographs with their Mylar overlays scanned so as to show the photointerpreter's work. The assigned map class codes and the aerial photograph flight line numbers are in yellow or black depending on the visibility of the color on the photograph. Ground photos of each type are included where available. The photos are accompanied by a brief description of the distribution of the map class within the project area and how it generally appeared on the aerial photos. Other information about the map class or the polygon may be included if it improved understanding or recognition of that particular map class.

Merrick & Company of Aurora Colorado flew the color infrared (CIR) aerial photographs for SUCR on October 8, 1996. The photos were taken at a flight altitude of 6,000 feet above sea level using Kodak Aerochrome Infrared 2443 film. The photo mission was designed to take photos with about 30% side lap (between each flight line) and 60% overlap (along each flight line). The scale of the 9 x 9-inch photos is 1:12,000 (approximately 1 inch = 1000 ft.). Two sets of contact prints and positive transparencies were produced and used for stereoscopic interpretation. A total of 46 frames taken over 6 flightlines covered the project area.

Color Infrared Film (CIR)

CIR film is best for highlighting subtle changes in deciduous and wetland vegetation. Evergreen vegetation can also be distinguished using CIR film, although not as clearly as deciduous trees and shrubs. CIR film presents a "false color" picture that combines infrared reflectance with green and red visible bands. These differences in reflectance create differences in tone and color that can be easily distinguished and delineated as different plant communities. Reflectance is influenced by structure of the canopy, the orientation of the plants and their leaves, and the thickness and pigment content of leaves.

Texture is also important to the photointerpreter. For shrubs, texture is influenced by density of plants on the landscape, crown size and shape, and leaf size. Dense, medium-sized shrubs such as rabbitbrush give a grainy texture to the photographs. Small shrubs such as snakeweed show little or no texture, since the plants are about the same size as a small bunchgrass. Grasslands

tend to have a smooth texture, except where interrupted by prairie dog holes or anthills, which appear as pinhole-sized white dots. These are imprecise terms, but nonetheless provide important visual cues to the imagery.

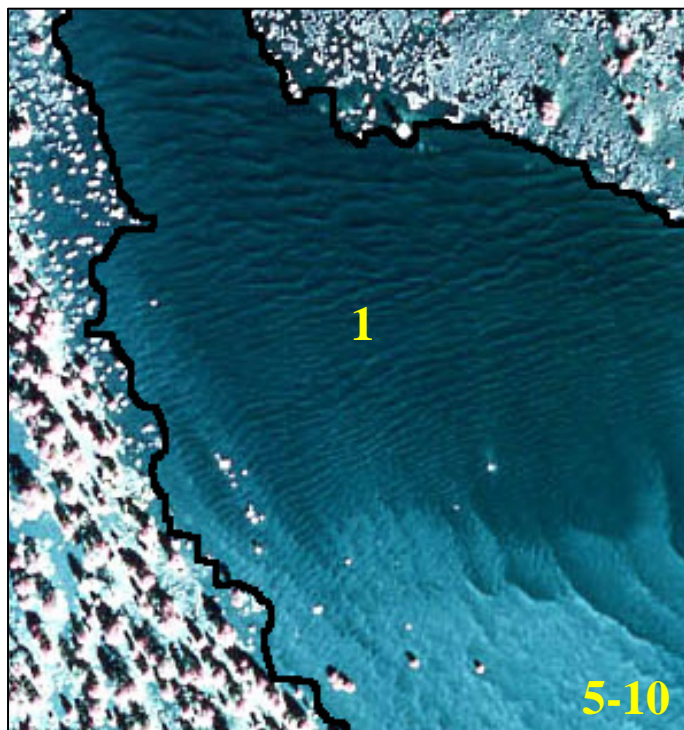
CIR photography generally is not consistent enough to allow a species or type to be described precisely. Film batch, printing process, sun angle, light intensity, shadow, and exposure can all affect the appearance of CIR photography. For accurate mapping at SUCR, ground verification by the photointerpreter was very important for to successful interpretation of types with confusing or similar signatures.

Cinder Sparse Mosaic (1)

Location. This map class is scattered in small and large patches throughout the eastern half of the mapping area. Smooth slopes and windblown dunes of sparsely vegetated black cinder characterize it.



Photosignature. This map class has a unique signature because it is largely unvegetated volcanic cinder. The color ranges from a very dark greenish-black to a pale blue green. The texture is generally smooth, but sometimes it has a wavy texture created by dune formations. Small inclusions of vegetation appear generally as white dots and specks.

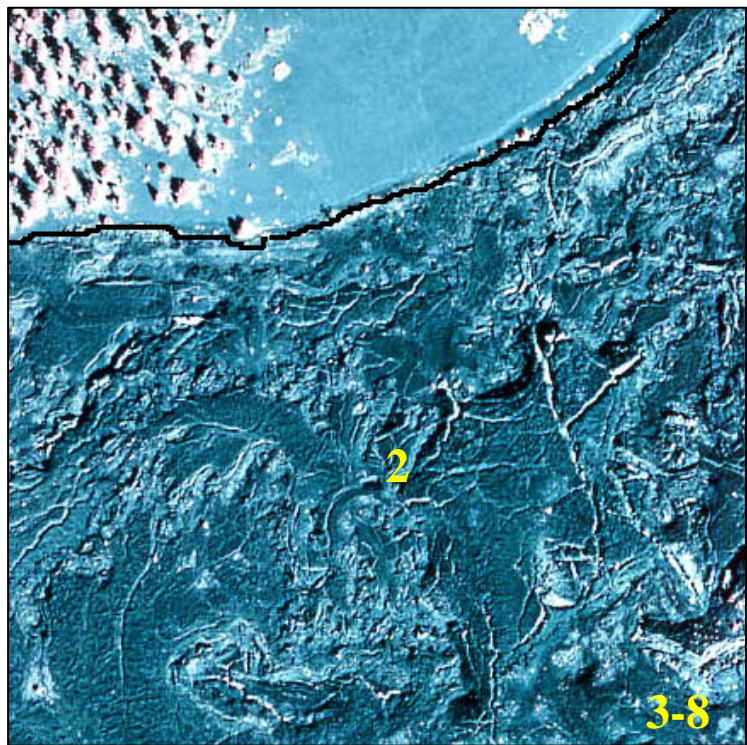


Lava Beds (2)

Location. This map class consists of the unvegetated portions of two large lava flows located near the center of the mapping area. It interfingers with map code 6 (Lava Bed Sparse Vegetation).



Photosignature. This map class has a unique signature because it is largely unvegetated lava flow. The color ranges from a very dark greenish-black to a pale blue green. The texture is rough and irregular, reflecting the broken surface of the lava. Small inclusions of vegetation appear generally as white dots or specks or as light blue-green smudges. Some areas of the flow were subsequently covered by volcanic ash and cinder; these areas appear smoother and much darker, and are often vegetated (not visible on this photograph).



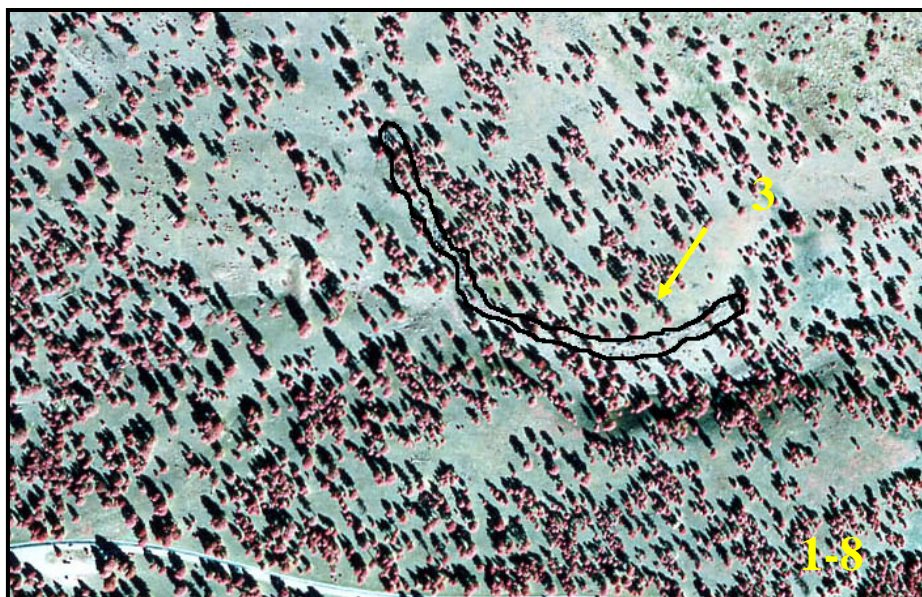
Rock Outcrop and Scree Shrubland (3)

Location. This map class consists of a complex of shrubland plant communities characterized by their preference for rocky substrates. It occurs in very small polygons scattered throughout the mapping area.



Photosignature.

Only the larger occurrences of this type were visible on the aerial photos; even so, most are less than the minimum mapping unit in size. They appear as breaks in the dominant vegetation, characterized by a grayish color and rough texture. Some, as in the example pictured here, are linear in shape and partly obscured by trees.

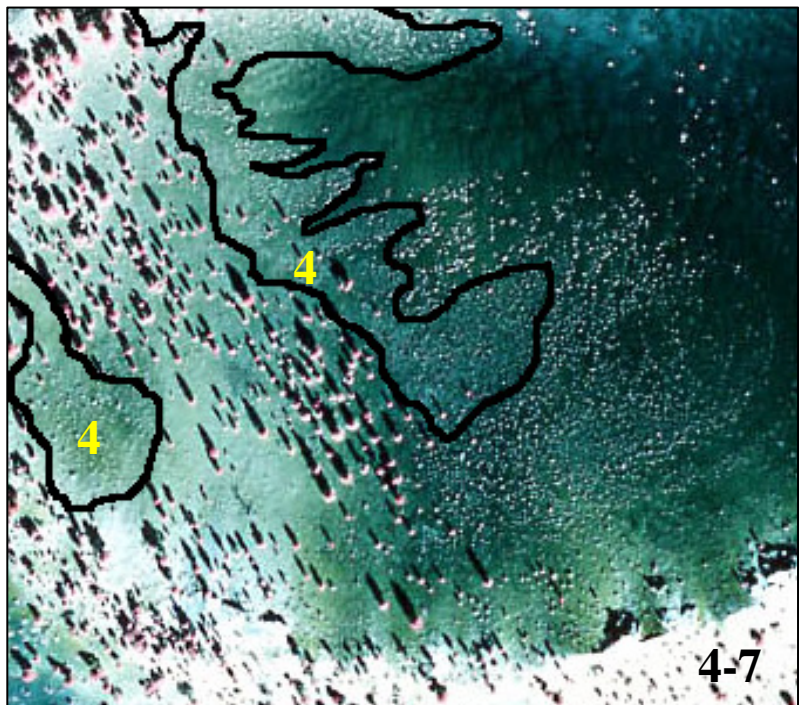


Wild Buckwheat – Sand Bluestem Sparse Vegetation (4)

Location. This map class occurs in small polygons scattered in areas of deep cinder deposition. The best occurrences are on the upper parts of the Sunset Crater cone and in the northeastern part of the mapping area. The vegetation consists of the two named species with little other vegetation present.



Photosignature. For the most part, occurrences were mapped from direct field observations. This type is very similar in appearance to map code 7, Sand Bluestem Herbaceous Vegetation, which often occurs in adjacent polygons. The cinder substrate gives the map class a greenish-black color, while the vegetation contributes a blue-green cast (the grass) with tiny white specks (the shrubs).

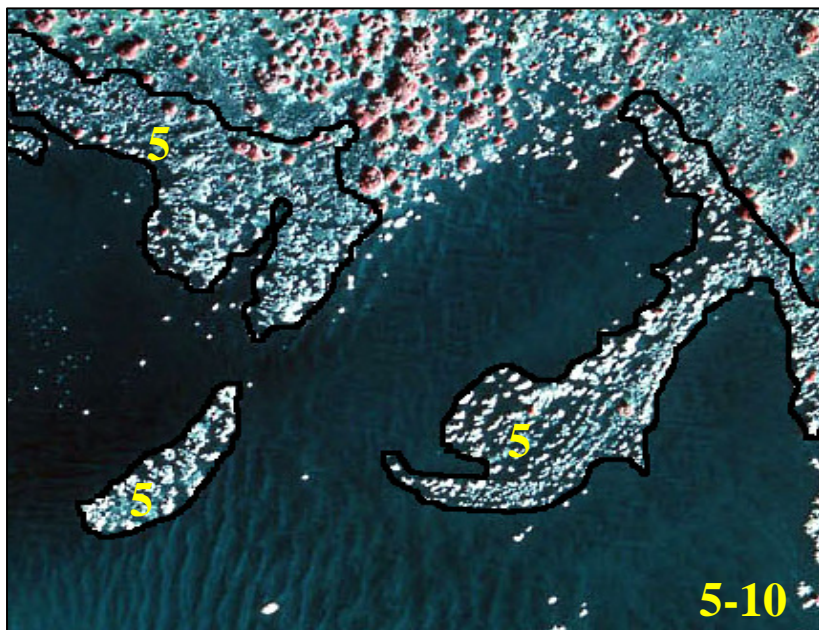


Apache Plume / Cinder Sparse Vegetation (5)

Location. This map class is common and widespread, except in the southwestern corner and the western edge of the mapping area. It is best developed on lava outcrops mixed with volcanic cinder. It consists of sparse to dense stands of apache plume, generally with few associated species.

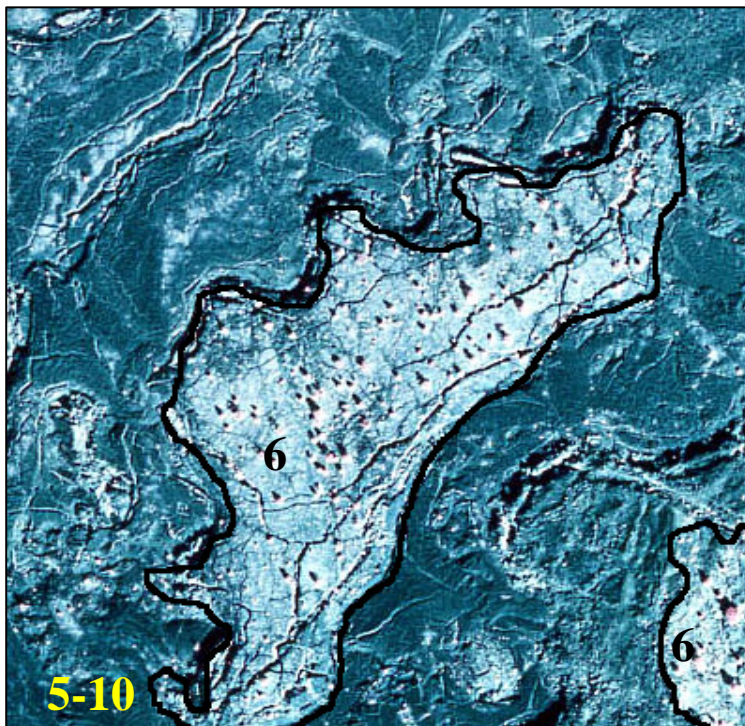


Photosignature. The characteristic signature for this map class consists of irregular small grayish white to blue-white speckles set in a matrix of smooth black cinder or rough black lava. The pink dots of trees are very sparse or absent.



Lava Bed Sparse Vegetation (6)

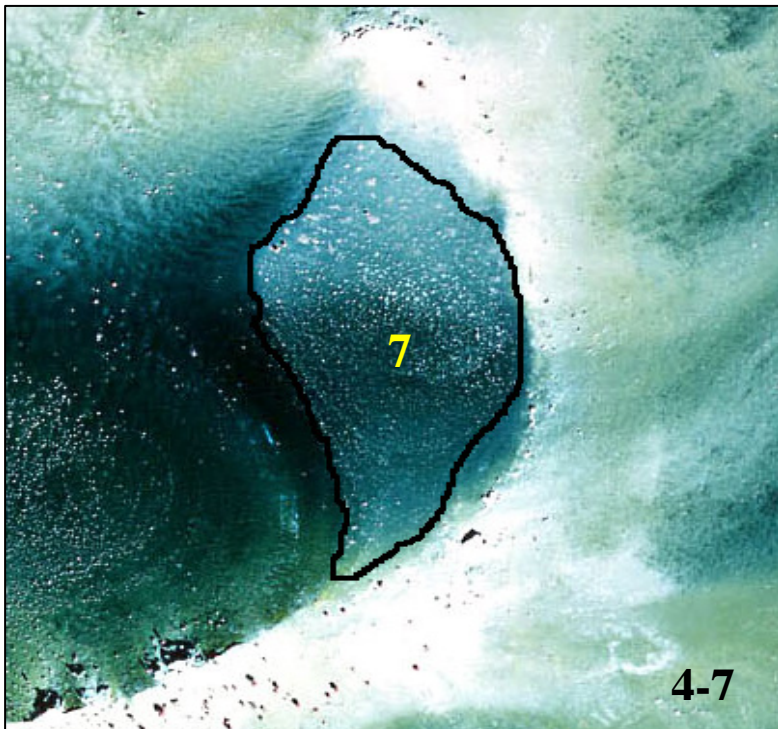
Location. This map class is closely associated with map code 2 (Lava Beds). It includes small patches of several different kinds of vegetation, including aspen woodlands, ponderosa pine woodlands, apache plume shrublands, and mixed shrublands that include ocean spray. It is generally restricted to the lava flows near the center of the mapping area.



Photosignature. Because of the variety of plant communities included within this map class, the signature is also somewhat variable. The map classes are associated with the two large lava flows, so they are either within or along the margins of the flows. The map class appears as a light bluish-white patch, with a gritty texture if shrubs are present, or small red-brown dots where aspens or ponderosa pines grow. This example is from the large lava flow north of the main park road.

Sand Bluestem Herbaceous Vegetation (7)

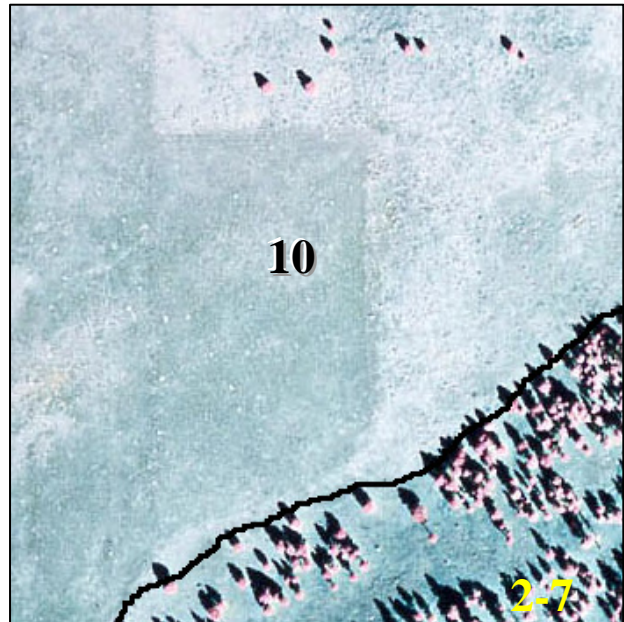
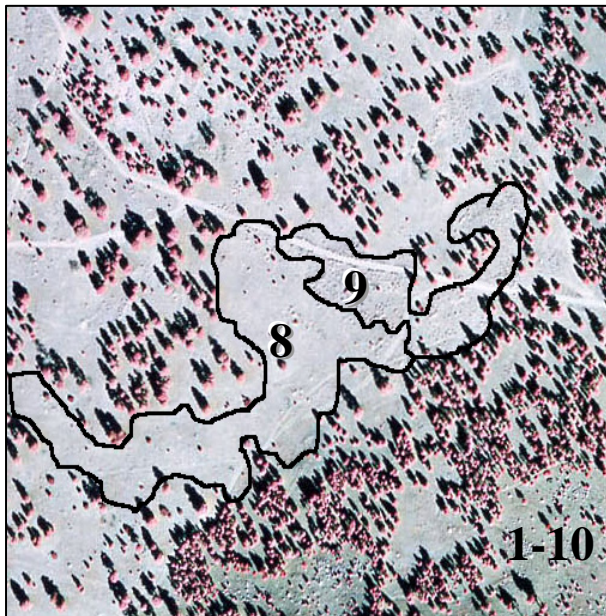
Location. This map class is restricted to cinder slopes on the eastern and southern flanks of Sunset Crater. It consists of sparse but nearly pure stands of sand bluestem growing in volcanic cinder.



Photosignature. The characteristic signature for this map class consists of minute grayish white to blue-white specks set in a matrix of smooth greenish-black cinder. A thin litter layer sometimes imparts a whitish cast to the matrix. The texture of the specks is generally finer and more regular than that of map codes 4 or 5. This example is from the rim of Sunset Crater.

Montane Grassland (8-10)

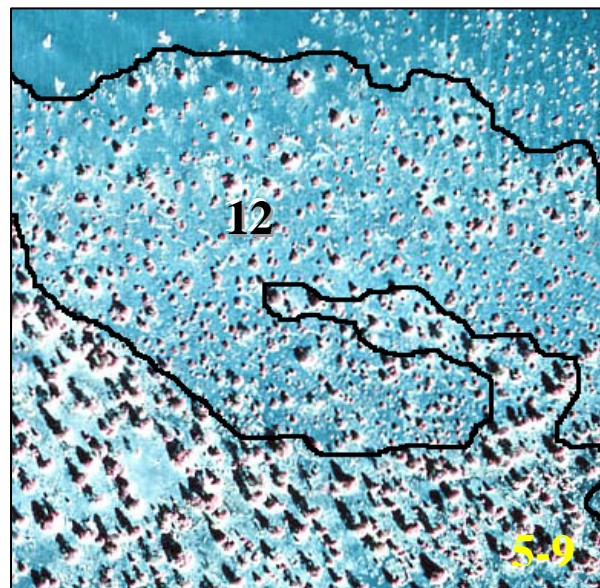
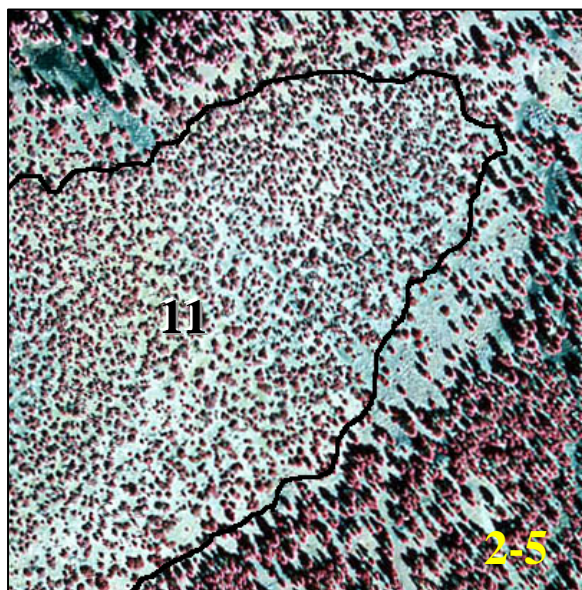
Location. This map class is best developed in the western part of the mapping area. It includes native grasslands of blue grama and mountain muhly as well as more disturbed situations that include stands of rabbitbrush or native forb species (such as Bonito Park).



Photosignature. Native bunchgrass grasslands (8) appear as light gray, smooth patches, usually within areas of ponderosa pine or other woody vegetation. Stands of rabbitbrush (9) are distinguishable by the texture of the small bumps the shrubs create. Bonito Park (10) forms a single class, marked by the presence of fence lines and lines marking the edge of old fields, visible in the center of the right picture.

Pinyon Pine – Utah Juniper / Blue Grama Woodland (11-12)

Location. This map class occurs in large patches on the slopes of the cinder cones within the mapping area. There are also stands on the windswept upper slopes of some of the larger cinder cones in the area. The understory is usually poorly developed, but may include sparse grasses or shrubs. Areas with more open pinyon-juniper canopy generally have a better-developed understory.



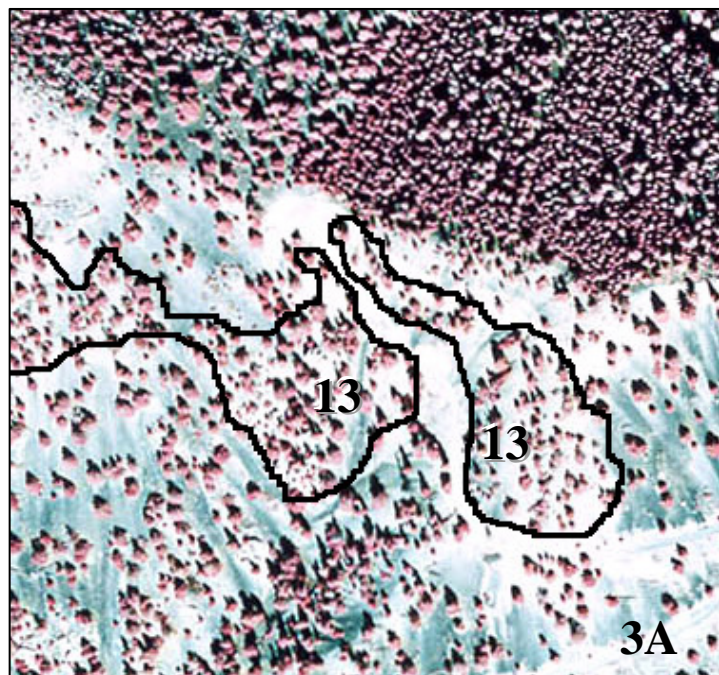
Photosignature. Mature pinyon pines and Utah junipers (11) are easily distinguished from ponderosa pine by their flatter, more irregular crowns and generally shorter stature (little or no shadow). Sparse stands (12) generally have a significant cover of shrubs, including skunkbush sumac (*Rhus trilobata*) and apache plume (*Fallugia paradoxa*), which contribute a rough texture to the appearance of the understory.

Limber Pine Woodland (13)

Location. This map class is restricted to small polygons on the exposed, south-facing upper slopes of O’Leary Peak.

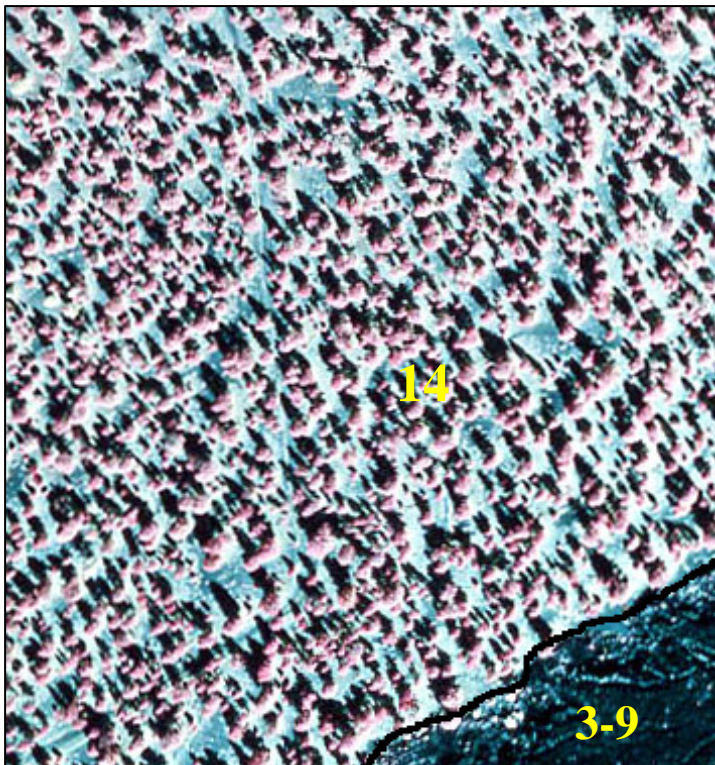


Photosignature. This map class was mapped from field observations. In general the appearance is similar to that of sparse pinyon-juniper stands (12), except that the individual tree crowns tend to be taller and broader. The understory is generally sparse, but appears white because the ground is covered with litter. The pictured example is from the shoulder of O’Leary Peak below the summit ridge.



Ponderosa Pine / Cinder Woodland (14)

Location. This map class is widespread, occurring in large areas in a north-south belt separating map codes 15 (Ponderosa Pine/Montane Grass Mosaic) and 17 (Ponderosa Pine/Apache Plume). While scattered clumps of grass or shrubs may occur in the understory, the general ground cover is barren cinder. This type contains most of the known populations of the rare beardtongue (*Penstemon cluteii*).



Photosignature. Ponderosa pines appear as reddish-brown spots, generally accompanied by significant black shadows. White patches, occurring around the base of individual trees, are the result of pine litter, not a grass understory. The ground between the tree crowns has the greenish-black appearance of barren cinder.

Ponderosa Pine / Montane Grass Mosaic (15)

Location. This map class is widespread, occurring in large polygons in the western third of the mapping area. Blue grama and/or mountain muhly may form a significant understory layer.

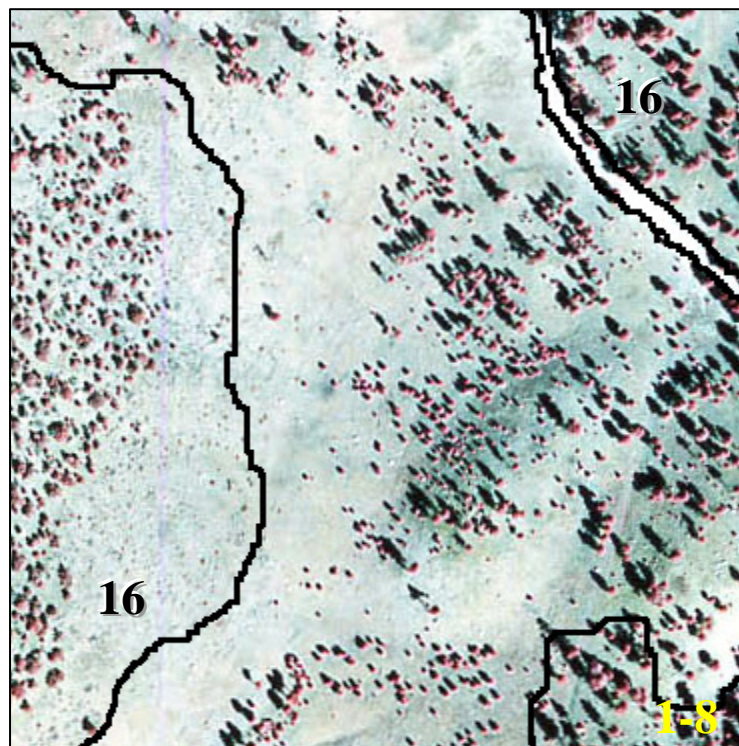


Photosignature. As in map code 14, ponderosa pine appears as reddish-brown spots accompanied by significant black shadows. The ground between the tree crowns usually appears uniformly light gray because of a combination of grass understory and pine litter. This example is immediately north of Bonito Park. The type may contain small inclusions of map code 17 (Ponderosa Pine/Apache Plume) and map code 14 (Ponderosa Pine/Cinder).



Ponderosa Pine Invasive Herbaceous Vegetation (16)

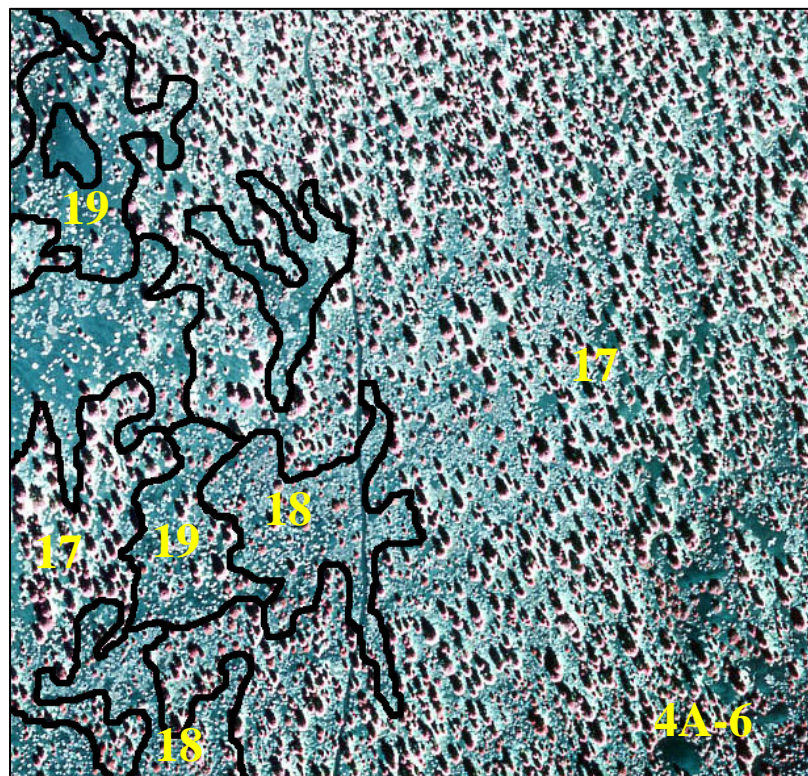
Location. This map class occurs in large polygons in the west central part of the mapping area, in parts of the area that burned 5-30 years ago, along disturbed roadsides and in the vicinity of the larger gravel pits. In these areas, invasive, non-native species became dominant in the understory, forming dense herbaceous stands where trees were killed, and forming the understory in areas where the canopy trees survived.



Photosignature. This map class is a mixture of wooded and herbaceous vegetation. As in map code 14, ponderosa pines appear as reddish-brown spots, generally accompanied by long black shadows. Some areas lack tree cover; many of the burned trees have fallen and appear as narrow gray lines on the light yellowish-gray of the invasive herbaceous vegetation.

Ponderosa Pine / Apache Plume Woodland (17-19)

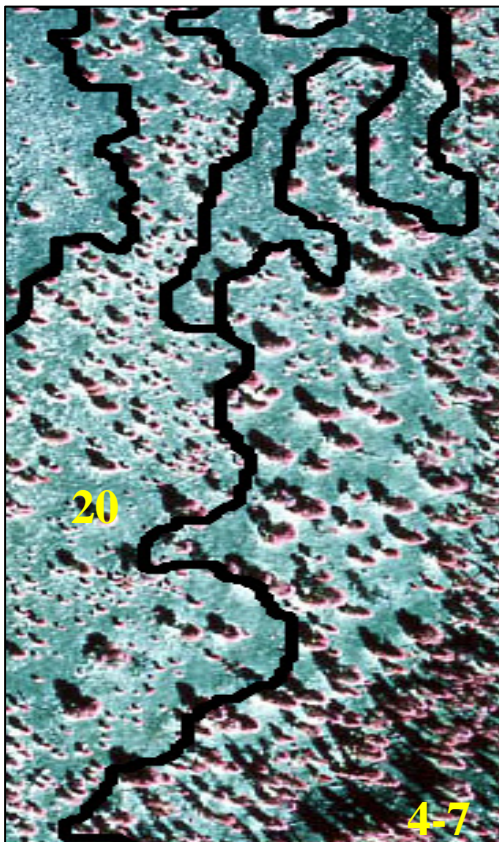
Location. This common and widespread map class occurs in large polygons throughout the mapping area, although most of the type is in the eastern half of the area. Apache plume shrubs and sometimes rabbitbrush shrubs form a significant understory in open ponderosa pine woodlands.



Photosignature. In the best developed examples (17), ponderosa pine appear as red-brown spots, usually associated with larger, oblong black shadows. The understory appears rough-textured because of the shrubs. Rabbitbrush shrubs are small, white, somewhat fuzzy round specks, whereas Apache plume appears as irregularly-shaped white or red-brown specks. The dark cinder/lava substrate is more evident in examples with a sparse ponderosa overstory (19). Mixed ponderosa-pinyon-juniper examples (18) tend also to have a sparse overstory of trees.

Ponderosa Pine / Sand Bluestem Woodland (20)

Location. This map class is best developed outside the park boundary. However, a few small polygons occur within the mapping area, on the flanks of Sunset Crater and smaller cinder cones in the vicinity. This class was mapped primarily from observations made in the field.



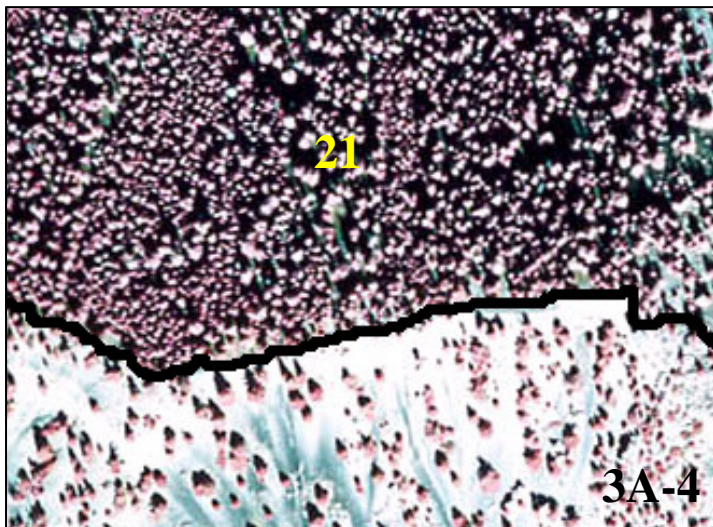
Photosignature. There is little in the aerial photosignature to distinguish this type from map code 14 (Ponderosa Pine/Cinder Woodland) or map code 15 (Ponderosa Pine/Montane Grass Mosaic). Because the canopy is usually open, the grass understory sometimes appears as regularly spaced tiny white specks against the greenish-black cinder substrate.

Douglas-fir Forest (21)

Location. This map class includes all stands where Douglas-fir is dominant or co-dominant with ponderosa pine or limber pine. Within the mapping area, this type is restricted to steep, north-facing upper mountain slopes on lava and mixed lava-cinder substrates.



Photosignature. The principal distinguishing characteristic of this map class is the dense, dark canopy of red-brown trees with consistently pointed crowns. Very little of the black cinder/lava substrate is visible. When viewed in stereo, the steepness and northerly aspect of the habitat is evident. This example is from the summit ridge of O'Leary Peak.

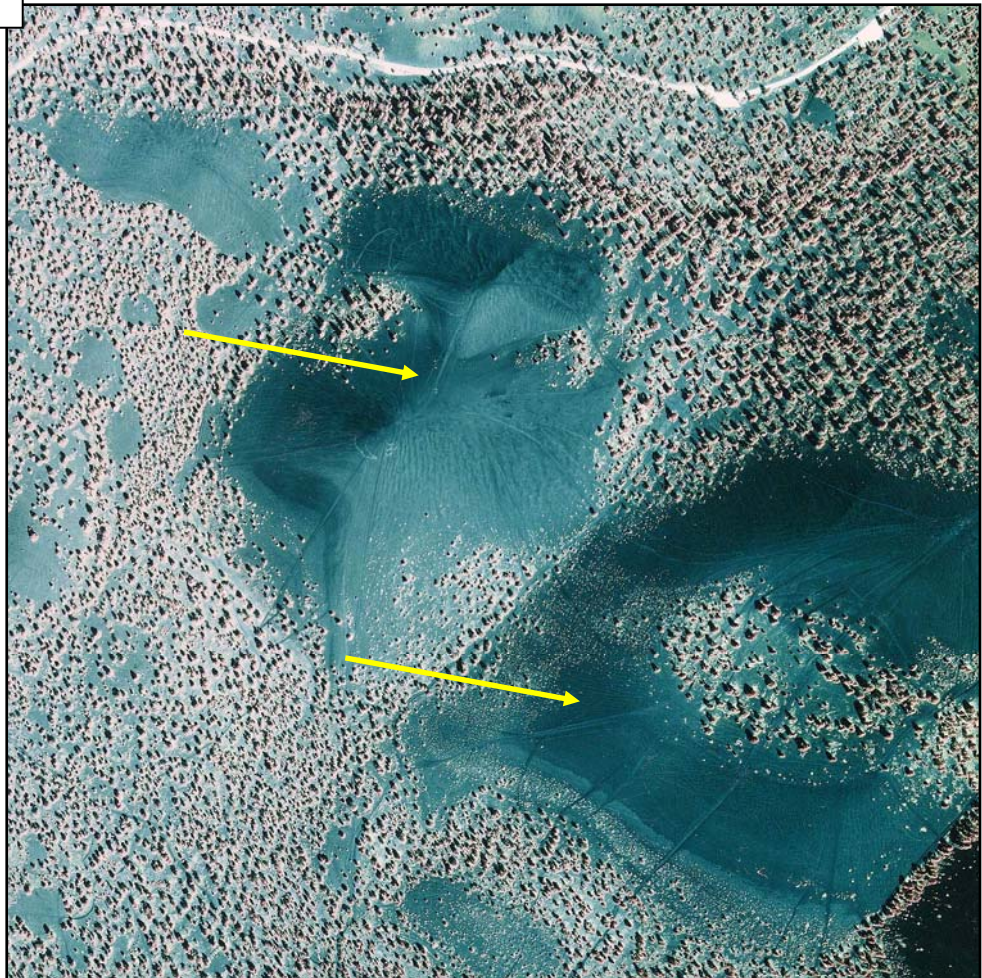


OTHER MAPPING COVERAGES

OFF-Highway Vehicle (OHV) Class

Location. The OHV Class was used to delineate disturbed areas surrounding SUCR. The highest concentration of OHV use appeared in the south, east and northeast portions of the project area.

No Ground Photo



Photosignature. This class is characterized by having linear lines resulting from temporary tracks left by OHVs. Tracks usually cross and radiate from a common starting point, usually an established road, pull-out or parking lot. Tracks on cinders appear slightly lighter than undisturbed sites. Tracks through vegetation usually expose the cinder substrate.

Quaking Aspen / Cinder Woodland

Location. The Quaking Aspen / Cinder Woodland Class was used to delineate small stands of aspen (*Populus tremuloides*) in and around SUCR. Only two patches were mapped using four polygons. One patch occurred within the monument just south of the Sunset Crater road on the north slope of Lenox Crater. The other patch occurred in the northwest portion of the study area in the project environs. Other scattered aspen stands were not big enough to map.



Photosignature. Aspen trees were difficult to distinguish from ponderosa pines due in part to their intermixing and the pale color of the infrared photography. Aspen trees canopies were slightly pinker than pines and appeared as “fluffs” rather than cones. Ground verification by the ecologists supplemented the photo interpretation for this class.